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Experimental Investigation of Compressive Behaviour of Pier by Partial Replacement of Metakaolin

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Abstract

Objectives: The main focus of our experimental investigation is to study the behavior of a pier based on variations in compressive strength due to partial replacement of cement with metakaolin in order to attain maximum stiffness and strength, so as to withstand the shear forces, bending moments and other related structural response parameters efficiently.

Analysis: The round and rectangular specimens were prepared by replacing cement with metakaolin up to 15%. The samples were tested after 7 and 28 days.

Findings: Study reveals that with the replacement of 10% metakaolin in both circular as well as rectangular moulds, there is an increase in the load carrying capacity approximately about 19%, when compared with plain reinforced concrete moulds after 28 days. The most important finding is that the replacement of cement by metakaolin up to 10% helped us to attain higher strength after 7 as well as 28 days hence providing us a simple and efficient method of preventing the pier failure by attaining higher strengths.

Improvement/Applications: Based on the test results there is remarkable increase in the load carrying capacity of pier which enhances the rigidity of pier in terms of strength and stiffness.

Keywords Rectangular and circular pier; Compressive strength; Metakaolin; Cement

Introduction

Pier being considered as a member of life line structure needs to be stiff and strong throughout the life expectancy. Being a region of complex stresses and prone to the heavy loads that may be acting on, it needs to be the strongest member of the structure hence requiring the special attention for the stability of structure [1]. In recent times, many bridge piers have been damaged either by self-loads, or by earthquakes because of the reason of weak strength [2]. To maximize structure effectiveness as far as the quality/mass and stiffness/mass proportions and to lessen the mass commitment of the bridge to seismic reaction, it has been a prominent building practice to utilize bridge piers for column sections. Many existing RC piers don't satisfy the quality and ductility demands for seismic loading as they were designed in light of outdated codes of practice. Because of the lack of sufficient transverse reinforcement as well as appropriate seismic detailing, these substandard RC piers may encounter ductile shear failure (before or after the flexural yielding of longitudinal reinforcement),confinement failure of the flexural plastic hinge region and lap splice de-bonding of the longitudinal reinforcement during a major earthquake. As a result, they need large strength and ductility improvements in order to meet the requirements of modern earthquake-resistance regulations [3]. The variable forces that may be induced due to the vertical forces on the piers are not included in seismic codes. Due to major or minor earthquakes, the intensity of such forces can be so high that the compressive forces will be as large as thrice the dead load. Also severe tensile axial load can generate [4]. Compressive stresses due to direct tension leads to Vertical motion resulting failure in shear and flexure, hence reducing the moment capacity and ductility of RC columns or piers [5]. Designing of single-column type RC bridge piers as per the earlier IRC codes were investigated. In such cases, the load carrying capacities of short piers were found lower than the required shear demand for compressive and flexural strength conditions [6].Compressive stresses due to direct tension leads to Vertical motion resulting failure in shear and flexure, hence reducing the moment capacity and ductility of RC columns or pier in seismic zones, the efficiency of new RC structures could be improved by weakening the rebar and concrete bond [7,8]. Utilizing material of efficient properties (e.g. steel with high strain hardening), improving the reinforcement provided and proper section design can be a efficient step to increase the yield stiffness for section [9]. Replacement of some percentage of cement by metakaolin can effectively enhance the strength of concrete [10]. Metakaolin is exceptionally a viable pozzolanic material which adjusts the pore structure in concrete framework and enormously enhances the imperviousness to dissemination of harmful particles. Replacement of Metakaolin as fractional replacement of cement improved the compressive strength of concrete [11]. Metakaolin as a replacement in concrete exhibits favorable engineering properties, like, the acceleration of OPC hydration, and the pozzolanic reaction. With partial replacement cement by metakaolin (Supplementary cement material), the rate of compressive strength increases and hence providing efficient results at the final stage. With Metakaolin as partial replacement of cement, the compressive strength of concrete increases

[12]. Metakaolin in concrete reduces shrinkage, enhances particle packing, reducing efflorescence and hence increasing the overall performance of structure.

Materials and Methods

Coarse aggregate

Coarse aggregate used in experimental are combination of two nearby obtainable creased stone of 20 mm and 10 mm size in 55:45 fraction respectively. The specific gravity examined for 20 mm and 10 mm aggregate is 2.81 and 2.75 respectively.

Fine aggregate

Fine aggregate used for experimental work is of Zone II examined with IS: 383-1970, with specific gravity equal to 2.45.

Cement

In the present study OPC 53 grade cement is taken for design mix. The specific gravity examined is 3.15 and fineness 3%.

Metakaolin

In the present study metakaolin is used in powder form taken from a chemical factory.

Mix design for concrete

The aim of our research work is to investigate the response of pier due to partial replacement of metakaolin in cement. Ordinary potable water was used throughout the investigation as well as for curing concrete specimens. The typical water cement ratio used for the project work is 0.45. The different mixes prepared for experimental study is M25, the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm2 as per is 456-2000.

Figure 1: Circular mould=15 cm × 40 cm, Rectangular mould=15 cm × 15 cm × 40 cm.

Structure of specimen

In order to study the behavior of pier, the specimens were prepared in both circular as well as rectangular form. Overall dimensions of specimen are given in (Figure 1).

Experimental setup

The 16 rectangular and 16 circular piers were casted. The rectangular pier having the dimensions of 150 mm × 150 mm with the height of 400 mm and circular pier with diameter 150 mm and height 400 mm, were tested after 7 and 28 days. Compression testing machine (CTM) and UTM were used for testing. After the application of the load at the rate of 0.01 mm/sec, cracks were developed in the pier and load at failure was determined. In order to increase the strength of the pier, replacement of metakaolin was done until 15% of replacement was made. The compressive strength was investigated for various proportions of metakaolin by using M-25 grade of concrete throughout the experiment. For both at various replacement levels of cement by metakaolin. A suitable arrangement is made at the time of testing for achieving the fixity condition as shown in (Figures 2 and 3).

The following table shows the detail of samples used during the research work. At a total 8 samples were used. The detail of sample is discussed in Table 1.

Sample	% age of metakaolin
Sample 1	For circular pier at 0% replacement of metakaolin
Sample 2	For circular pier at 5% replacement of metakaolin
Sample 3	For circular pier at 10% replacement of metakaolin
Sample 4	For circular pier at 15% replacement of metakaolin
Sample 5	For rectangular pier at 0% replacement of metakaolin
Sample 6	For rectangular pier at 5% replacement of metakaolin
Sample 7	For rectangular pier at 10% replacement of metakaolin
Sample 8	For rectangular pier at 15% replacement of metakaolin

Table 1: Details of samples used.

Figure 2: Testing of Rectangular column on UTM.

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Figure 3: Testing of circular column on CTM.

Results and Discussion

Using metakaolin as a partial replacement of cement increased the load carrying capacity hence increasing the strength of pier. In our project work up to 15% of cement was replaced by metakaolin with results were taken after 7 and 28 days respectively. During the research work a total of 8 samples (4 each from square and circular cross section) were taken with cement being replaced up to 15%. At 10% replacement level of cement by metakaolin, the increase in compressive strength obtained was most efficient with the percentage increase of 19.23% in circular and 16.76% in rectangular pier after 28 days. In order to find the compressive strength both compressive tensile machine (CTM) and universal testing machine (UTM) were used for tests performed. In order to calculate the compressive strength of both circular and square piers the peak load carrying capacity was calculated with the help of CTM and UTM. The peak load capacities of the samples are compared in Table 2.

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Peak load after 7 days	385.73 KN	421.72 KN	450.33 KN	422.25 KN	453.15 KN	474.75 KN	519.07 KN	465.52 KN
Peak load after 28 days	612.27 KN	661.19 KN	728.47 KN	642.82 KN	719.32 KN	776.7 KN	857.7 KN	757.35 KN

Table 2: Peak load comparison of samples after 7 and 28 days.

Sample	Compressive strength for 7 days(N/mm^2)	Compressive strength for 28 days(N/mm^2)
Sample 1	21.84	34.67
Sample 2	23.88	37.44
Sample 3	25.50	41.25
Sample 4	23.91	36.40
Sample 5	20.14	31.97
Sample 6	21.10	34.52
Sample 7	23.07	38.12
Sample 8	20.69	33.66

Table 3: Compressive strength of various samples after 7 and 28 days.

After finding the peak load carrying capacity of piers by performing various tests on CTM and UTM respectively after 7 and 28 days, the following resulted were found out showing the compressive strength of each sample after 7 and 28 days (Table 3).

From the above results significant increase in the compressive strength of both circular as well as rectangular piers was obtained after the partial replacement of cement by metakaolin. These readings were calculated after the peak load capacity of the pier was tested by performing compressive strength test.

The below graphs show the comparsion of compressive strength according to percentage of metakaolin after 7 and 28 days (Figures 4 and 5).

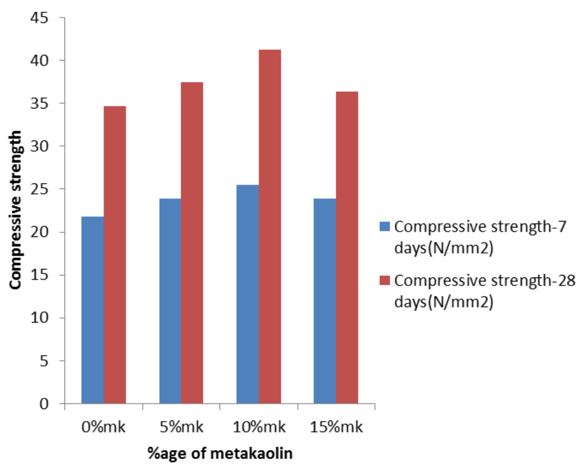

Figure 4: Circular pier.

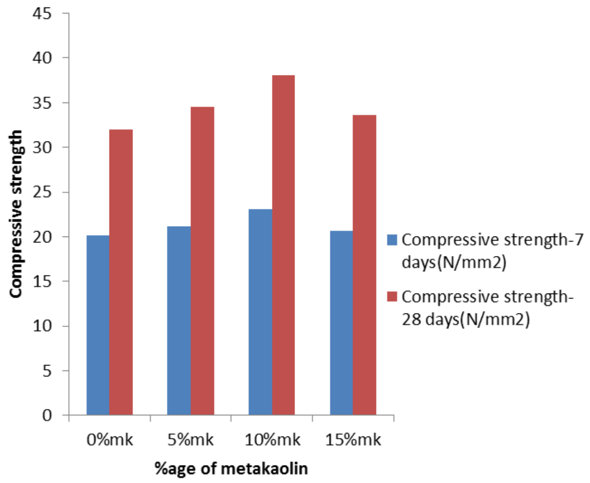

Figure 5: Rectangular pier.

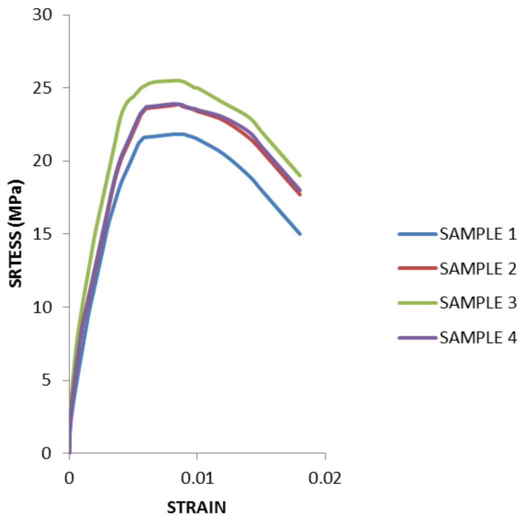

Figure 6: Stress-strain relation after 7 days (circular pier).

After calculating the compressive strength of each and every sample, in order to find the stress-strain relationship of circular and square piers after 7 and 28 days the following figures were plotted (Figures 6-9).

The close agreement between the fitted curves and experimental data indicates that Figures 6-9 can be used to represent the complete stress-strain relationship in compression.

Figures 6-9 are proposed to represent the complete stress-strain relationship of concrete pier in compression.

These equations fit a wide spectrum of experimental data remarkably well and show the ascending and descending branches of the stress-strain curve.

The shape of the stress-strain curve and its parameters are affected by the testing conditions and concrete characteristics.

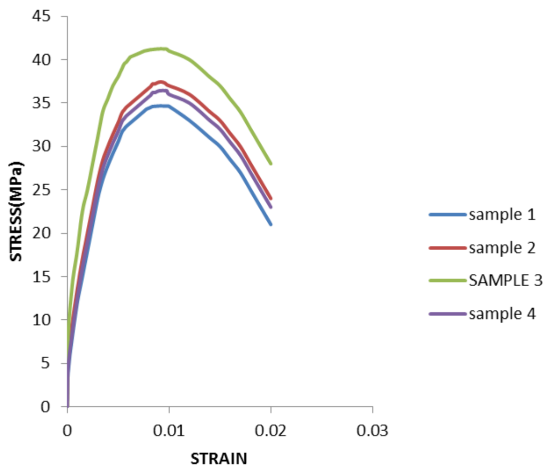

Figure 7: Stress-strain relation after 28 days (circular pier).

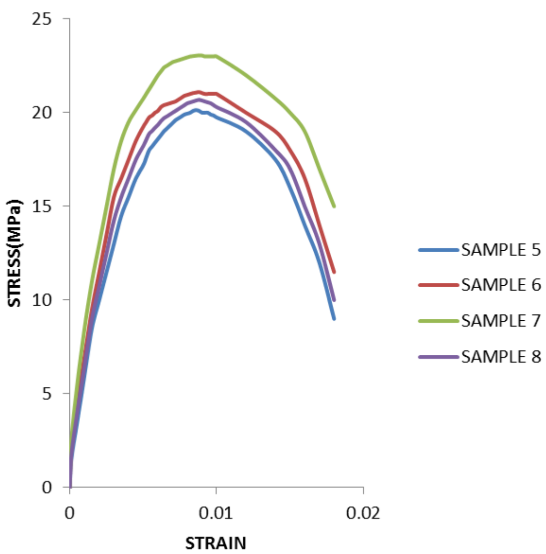

Figure 8: Stress-strain relation after 7 days (Rectangular pier).

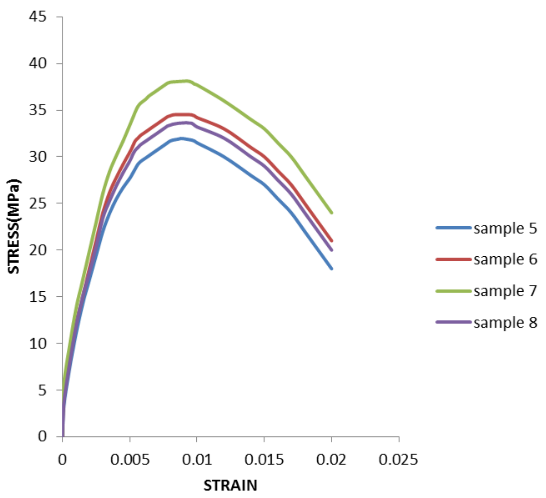

Figure 9: Stress-strain relation after 28 days (Rectangular pier).

As in the above cases, for circular pier after 7 and 28 days, the sample 7 is having the highest stress values hence suggesting that concrete when replaced with 10% of metakaolin can attain more compressive strength as compared to other samples. Same was case in rectangular piers, the pier sample replaced with 10% metakaolin showed higher stress values, hence suggesting to increase in compressive strength in such cases.

Conclusion

- Sample 3 is having superior load carrying capacity which is 19.06% more as compared sample 1, 11%, more as compared to sample 2 and 13.98% more as compared to sample 4 after 28 days.
- Sample 7 is having superior load carrying capacity which is 19.23% more as compared to sample 5, 11.26% more as compared to sample 6 and 13.95% more as compared to sample 8 after 28 days.
- Sample 3 is having superior load carrying capacity which is 16.76% more as compared sample 1, 7.4% more as compared to sample 2 and 7.42% more as compared to sample 4 after 7 days.
- Sample 7 is having superior load carrying capacity which is 14.54% more as compared to sample 5, 9.78% more as compared to sample 6 and 10.89% more as compared to sample 8 after 7 days.
- The maximum optimal increase in the compressive strength was obtained at 10% replacement of metakaolin after 7 and 28 days.
- Addition of metakaolin improved the early strength as well as final strength by efficient amount.
- Load carrying capacity of circular pier was much efficient as compared to rectangular piers. Hence can with stand to more load.

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