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Performance Evaluation of Strength and Durability of Cement Mortar with Ceramic waste Powder and Bacterial Solution

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Abstract:
This paper reports the experimental investigation of partial substitution of cement with ceramic waste powder and water-cement ratio with bacterial solution. The entire investigation was carried out in two phases. In 1st phase, cement was substituted with ceramic waste powder and in the 2nd phase, along with the cement, 50% of water-cement ratio was also substituted with the bacterial solution. The water-binder ratio was kept constant at 0.32 throughout the investigation. The compressive strength, UPV and pH values of the samples were investigated after 3, 7, 28 and 56 days of curing. The 1st phase results showed a decline in the compressive strength as well as in the UPV values. At 10% substitution the decline was not very much significant but reached to around 40% at 50 percent substitution. In the 2ndphase, 10% and 20 % cement substitution with ceramic waste powder has shown significant improvement in the compressive strength as well as in UPV values. At 10 % substitution, the increase in strength was around 45% for both 7 and 28 days of curing. The pH value of the samples in the second phase at 3, 7, 28 and 56 days of curing was between 11.30 – 12.52.

Keywords: *Ceramic Waste Powder, Bacterial Solution, Compressive Strength, UPV, pH.*

1. INTRODUCTION

Cement produced for the utilization in the cement-based construction activities also generates an equal amount of carbon-di-oxide in the atmosphere(Leung et al., 2014) which in turn is responsible for several devastating phenomena such as ozone layer depletion, global warming etc. causing imbalance on earth. Per capita consumption of cement in India is estimated to around 190kg which is expected to reach 350kg(Gettu et al., 2019). This, of course, is an indication of the need for unconventional material to substitute the cement. The ceramic waste powder possesses pozzolanic properties and can be used to partially substitute cement (Ay et al., 2000; Heidari et al., 2013; Renato et al., 2015; Vejmelková et al., 2012) in cement mortar. There are some research works which concluded that ceramic waste powder at early stages do not reflect the pozzolanicbehaviour but while showed pozzolanic activity at late ages(Pokorný et al., 2014; Vejmelková et al., 2014). In India, the production of ceramic waste per year is estimated to be around 1000 lakh tons, where 15-30 % of waste is generated on account of the production of raw materials(Kumar et al., 2018; Raval et al., 2015). Concrete manufactured by replacing 10% cement with the ceramic waste, on

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curing under the standard water showed satisfactory results as compared to the others and also produced more (or) less same results as that of conventional concrete. Recently, scientists have found a way to incorporate wonder-material graphene into concrete, greatly increasing the material's strength and water resistance (Kumar et al. 2019, Kumar et al. 2020, Kumar et al. 2020).M FaizanDhrolwala et al. investigated that when 5% of the ceramic waste powder is added as a substitute to cement, the compressive strength gets reduced by 3.18%, on the other hand combining both 5% ceramic powder and 15% ceramic waste as replacement of cement and normal aggregate respectively, 3.68% reduction in strength occurs, therefore the use of ceramic waste becomes economically and technically feasible(Dhrolwala et al., 2018). S. Soundharya suggested that strength due to applied compressive load reduces owing to the pores inside the cement mortar on account of the process of consolidation, because of the phenomenon of microbiologically induced calcite precipitation(S. Soundharya and Nirmalkumar, 2014). Use of bacteria in mortar improves its strength(Gavimath et al., 2012; P. Ghosh et al., 2005; Vempada, 2011). Some bacteria have a better survival rate in the alkaline environment of concrete and produce better results in terms of strength and the best results in terms of strength are obtained at a bacteria concentration of 10^5 to 10^7 per millilitres(S. Ghosh et al., 2009; Sahoo et al., 2016). In order to make bacteria effortlessly stay alive in an alkaline environment, they are extracted from the completely alkaline atmosphere using $Ca(OH)_2$ which serves as the main source of cement (Singh et al. 2020). Bacillus bacteria which are a strain of CNBT-2 (Tripathi et al., 2017, Gupta et al. 2020)were inoculated.

In the present work, ceramic waste is used as pozzolans which is a class of non-metallic and inorganic solids that have undergone high temperature during the manufacturing of ceramics products. For the ceramic products in which the clay content exceeded 20%, the ceramic waste powder available is passed through 90 microns sieve and is then used as a substitute for cement. Bacteria used in this research are the microbial urease hydrolyses urea.

2. MATERIALS

2.1 **Cement**

OPC of grade 43(Bureau of Indian Standards, 2013) has been adopted in preparing all mortar specimens. It has been tested for various properties and the values are listed in Table 1 below.

Table1.Test result of Ordinary Portland Cement (OPC)

S.N	Properties	Value
1	Consistency	32%
2	Setting time (Initial)	96 minutes
3	Setting time (Final)	240 minutes
4	Sp. Gravity	3.10

2.2 Sand

Sand confirming to IS Code 383-2016(Standards, 2016) is used. All the particles with sizes greater than 1.18mm were first removed by sieving through sieve. It is also then tested for its various properties and the values obtained are shown in Table 2 below.

Table2. Test result of sand

S.N	Characteristics	Value
1	Category	Natural
2	Fineness Modulus (FM)	2.907
3	Grading Zone	III
4	Sp Gravity	2.65

2.3 Ceramic Waste

It is used as pozzolanic material and is a class of non-metallic and inorganic solids. In the present work the ceramic products whose clay content exceeded 20% are used. These ceramic products are ground to a fine powder and are then passed through 90 microns sieve before using it for partial substitution of cement in cement concrete. The properties of ceramic waste used are shown in Table3 below. Figure2 represents the XRD of ceramic waste powder and Figure3 represents the SEM image of the waste powder.

Table3. Ceramic Waste Properties

Chemicals	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**Cl**	**CaO**	**SO_3**	**MgO**	**LOI**
Contents	**70.18**	**14.79**	**0.90**	**0.30**	**1.65**	**0.60**	**0.57**	**1.82**
Colour	**White**							
Specific Gravity	**2.45**							

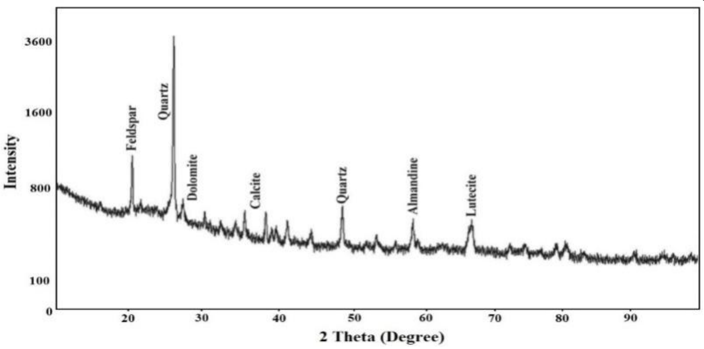

Figure1. XRD of Ceramic Powder

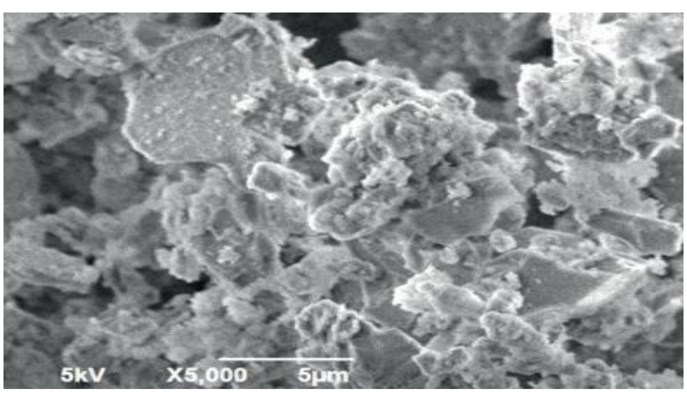

Figure2. SEM Image of Ceramic Powder

2.4 Bacterial Cultivation

Bacillus sphaericus was cultured under aerobic modified medium. 1000 ml bacterial solution was prepared. In 1 ltr of water nutrient broth added as 13gm and kept for autoclaving. After that 79.09 gm of $CaCO_3$ was mixed in this solution. The above solutions were mixed together. 25 ml of calcium acetate and 50 ml of urea were then added in 1 ltr of solution. Then at last 10 % of bacterial strains were added in 1 ltr of the solution to obtain complete bacterial culture. The culture so obtained was kept in a shaker for 24 hrs.

3. EXPERIMENTAL WORK

3.1 Compressive Strength

The test was performed using the CTM on cubes of 70.6mm × 70.6mm × 70.6mm size having cement sand ratio 1:3 with w/c ratio 0.32 confirming to IS 4031 (PART 6): 1988(Bureau of Indian Standards, 1988). The mortar cubes were cured for 3days, 7days, 28days and 56days. The ceramic waste powder was added as 0, 10, 20, 30, 40 and 50 percent by weight of cement. For BCM mixes w/c was replaced by 50% of bacterial culture at a different proportion of ceramic waste powder.

3.2 Ultrasonic Pulse Velocity Test

The UPV test method as defined in the code IS 13311 (Part 1): 1992(Bureau of Indian Standards, 1992) has been conducted on all the samples at 3, 7, 28 and 56 days. The testing assembly comprises of a pulse-receiver unit which is equipped with an in-built data acquisition system and 2 transducers of 150 kHz

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central frequency. Through transmission, UPV measurements were undertaken with the transducers resolutely coupled to the opposite ends of the mortar sample using petroleum jelly as the coupling between the transducer and the samples.

3.3 pH

The pH test, on microbial ceramic waste mortar specimens at 3, 7,28, and 56 days using pH meter has been performed. In this test 1: 9 ratio of the crushed sample of mortar with water was considered. Different mortar mix designations are as given in Table4 below.

Table4. Designation of Mortar

S.N	Mortar Designation	Proportion
1	CCM	0%
2	CRM10	90% Cement + 10% Ceramic Waste
3	CRM20	80% Cement + 20% Ceramic Waste
4	CRM30	70% Cement + 30% Ceramic Waste
5	CRM40	60% Cement + 40% Ceramic Waste
6	CRM50	50% Cement + 50% Ceramic Waste
7	BCM10	90% Cement + 10% Ceramic Waste + 50% Bacterial solution + water
8	BCM20	80% Cement + 20%Ceramic Waste + 50% Bacterial solution + water
9	BCM30	70% Cement + 30% Ceramic Waste + 50% Bacterial solution + water
10	BCM40	60% Cement + 40% Ceramic Waste + 50% Bacterial solution + water
11	BCM50	50% Cement + 50% Ceramic Waste + 50% Bacterial solution + water

4. TEST RESULTS

Cement mortar cubes have been tested for the compressive strength and UPV values after curing of 3, 7, 28 and 56 days as per IS code specifications. The tests have been conducted on the conventional cement mortar, 1st phase mortar and 2nd phase mortar. In addition to above two tests, pH values of the mortar samples of 2nd phase has also been determined to check the effect of introducing bacteria on the alkaline nature of cement mortar. 1st phase test results have given reduced compressive strength as well as UPV values of cement mortar cubes while in the 2nd phase testing, the compressive strength as well as the UPV values showed a significant increase in the values.

4.1 Conventional Cement Mortar (CCM Mix)

At first, the conventional cement mortar without any substitution is prepared to measure its compressive strength and the ultrasonic pulse velocities in accordance to the IS codes. The values obtained are as shown in Table 5 below

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Table5. Test Results of Conventional Cement Mortar (CCM)

Days →	3	7	28	56
Compressive Strength (N/mm^2)	25.85	34.17	43.18	45.57
UPV Values (m/s)	3245	3552	3694	3720

4.2 First Phase Investigation (CRM Mix)

In the first phase, only cement is partially substituted with the ceramic waste powder for different percentages from 10 to 50. This mortar mix is designated as CRM mix. The strength and the UPV values of the mortar samples obtained are listed in Table6 below.

Table6. Compressive Strength (N/mm^2) and UPV values (m/s) of CRM mixes

Days → Mortar Mix↓	3		7		28		56	
	Comp. Strength	UPV	Comp. Strength	UPV	Comp. Strength	UPV	Comp. Strength	UPV
CRM10	25.70	3701	33.97	4008	42.02	4217	42.18	4054
CRM20	25.32	3649	30.92	3738	41.95	4249	41.65	4013
CRM30	21.95	3228	25.13	2957	36.00	3697	34.32	3394
CRM40	19.60	2951	22.44	2700	30.95	3152	30.32	2938
CRM50	15.53	2267	22.13	2693	27.48	2803	28.06	2719

4.2 Second Phase Investigation (BCM Mix)

In the 2nd phase, along with cement substitution with ceramic waste powder for different percentages, the water-cement ratio is also substituted with 50% bacterial solution. But the water-binder ratio is kept constant at 0.32. This mix is designated as BCM mix. The compressive strength, UPV and pH values of mortar samples obtained are listed in Table7 below.

Table7. Compressive Strength (N/mm^2) and UPV values (m/s) of BCM mixes

Days → Mortar Mix↓	3			7			28			56		
	Comp. Strength	UPV	pH	Comp. Strength	UPV	pH	Comp. Strength	UPV	pH	Comp. Strength	UPV	pH
BCM10	34.91	4998	11.41	49.86	5498	11.70	63.41	6184	12.08	61.71	5781	12.47
BCM20	31.26	4462	11.50	44.68	5295	11.73	59.40	5900	12.20	58.48	5536	12.43
BCM30	26.33	3791	11.42	37.66	4349	11.92	49.20	4989	12.02	47.47	4509	12.52
BCM40	25.07	3583	11.30	36.06	4206	11.61	45.90	4567	12.43	44.24	4222	12.51
BCM50	22.92	3317	11.35	33.10	3794	11.72	42.43	4123	12.35	41.53	4019	12.49

5. DISCUSSIONS

From Figure3 to Figure6, on comparing the test results of CCM cubes with CRM cubes and CCM with BCM, it was observed that for 1st phase mortar cubes the compressive strength got reduced as the degree of replacement was increased and the

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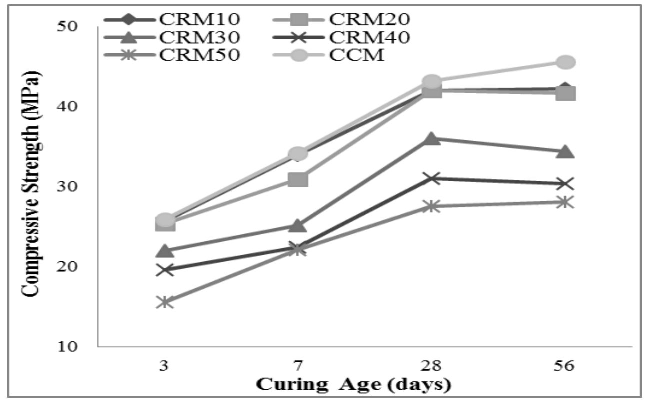
reduction was maximum at 50% replacement where the strength got reduced by almost 40% at 3 days of curing. Similar was the case with the UPV values. In the 2nd phase, the strength first increased for 10% replacement and then showed a decline on further increasing the replacement percentage. The maximum increase in strength of around 47% was observed at 10% replacement at an age of 28 days of curing. The UPV value for this case also showed an increase of around 41%. The pH value of the mortar cubes in the 2nd phase was observed to be in the range of 11.3 to 11.52. In the second phase at different combination of cement and ceramic waste, the water-binder ratio was also replaced by 50% of the bacterial culture and compressive strength and pH value of the mortar was measured. When the results obtained for the compressive strength of conventional mortar mix and the CRM mixes were compared, it was observed that on substituting cement with ceramic waste powder at different percentages, the compressive strength showed a reduction in strength. However, at 10% substitution the reduction was not very much significant. This reduction in strength can be explained on the basis of the UPV values of CCM and the different CRM mixes. When the conventional mortar mix was compared with BCM mixes, it was observed that the strength of the BCM mixes has shown improvements over conventional mix and the maximum strength improvement was achieved after 56 days for BCM10 mix. This increase in strength is on account of the microbiologically induced calcite precipitation (MICP). As the bacteria reacts with cement in the Mortar they form carbonate precipitates. As this reaction increases more and more carbonate precipitates are formed. These precipitates lead to the reduced porosity of the Mortar mix and hence an increased compressive strength. BCM-10 mix after 7 days has achieved maximum strength. This is because bacteria have completely adopted the Mortar environment and reacted well with cement forming more carbonate precipitates.



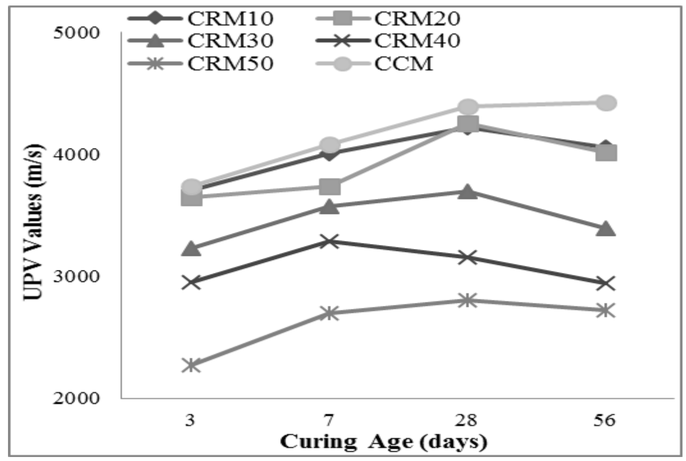
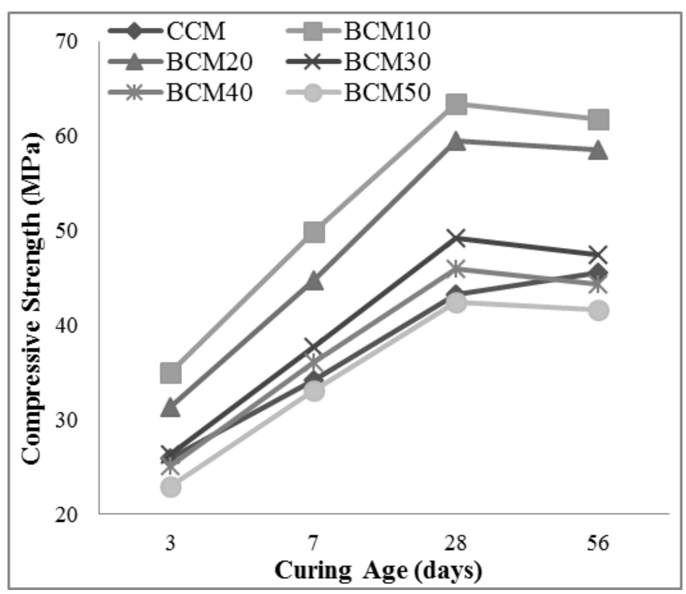


Figure3. Compressive Strength Comparison of CCM and CRM mixFigure4. UPV values Comparaison of CCM and CRM mixes



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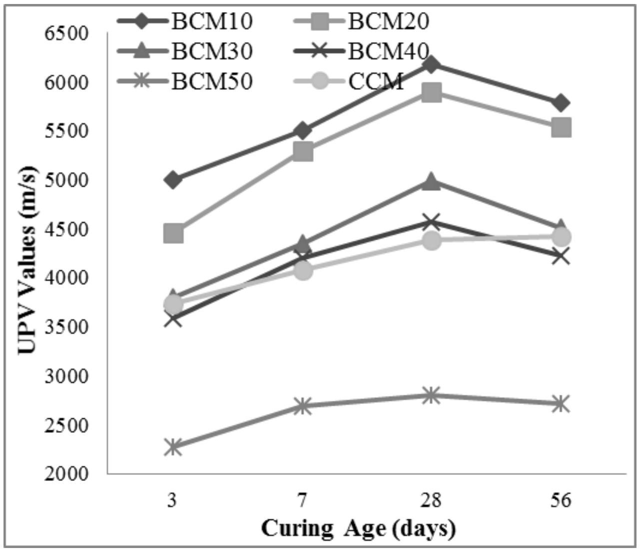

Figure5. Compressive Strength Comparison of CCM and BCM mixFigure6. UPV values Comparaison of CCM and BCM mixes

6. CONCLUSIONS

- The ceramic waste powder substitution with cement leads to a reduction in strength because of the increased porosity of the mortar mix.
- When ceramic waste was substituted with cement along with the replacement of water with 50% bacterial solution, the compressive strength of the mortar for 10% substitution with ceramic waste powder, was maximum after 56 days.
- About 45% increases in compressive strength after 7 days was observed for mortar with 10% replacement of ceramic waste along with the bacterial solution.
- High pH value gave an indicationmof the sustainable growth of bacteria in a highly alkaline environment.
- The ceramic waste powder was rich in silica and alumina (i.e. > 80%). In addition, the material was amorphous and particularly in the late ages showed pozzolanic behavior. Ceramic waste powder thus has strong potential to be used as an ingredient in the manufacture of eco-friendly concrete.
- With ceramic waste and bacteria solution replacement, the pH value of the mortar increasedup to 20% replacement of ceramic waste (i.e. BCM20), and then further starteddecreasing for higer % replacement mixes.

7. ACKNOWLEDGEMENTS

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