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RESEARCH ARTICLE

Implementation of paper mill waste as partial replacement material

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Abstract

Objectives: The objective of the study was to study the compressive strength of the partially replaced paper mill waste in cement. **Methods/ Statistical analysis:** The concrete cube specimen were prepared for compressive strength test. In this study, the cement has been replaced with 20%, 30%, 40% and 50% of hypo sludge. The specimens were cured for two different ages (7 days and 28 days) and tested for compressive strength. The quadratic polynomial prediction equation was proposed using Response Surface Methodology (RSM). The prediction model was developed using the experimental output results. Thus, the prediction model facilitates the further research work to be conducted by researchers on paper mill waste replacement. The rate analysis was also further carried out to show the cost effectiveness of using the waste replacement in cement. **Findings:** The test was conducted on the compressive strength (7 days and 28 days) of control specimen (0%) and partial replacement of 20%, 30%, 40% and 50% of cement using the hypo sludge. Thus, 20% replacement of cement using hypo sludge has shown good compressive strength than the control specimen. The cost of 20% paper mill waste was less when compared to the cost of control specimen. **Novelty/ Applications:** The compressive strength of 20% partial replacement of paper mill waste in cement can be used in further construction. The prediction model can be used to predict the future compressive strength of partially replaced paper mill waste concrete.

Keywords: Ordinary Portland cement; Paper mill waste; Hypo sludge; Partial replacement; RSM

1 Introduction

During the production of one ton of Ordinary Portland Cement (OPC), an equal quantity of carbon dioxide is released into the atmosphere which is destructive to our environment. So, there is a need to choose an alternative, in order to

avoid the damage to the environment[1]. To decrease cement usage in concrete, a paper industry byproduct like hypo sludge was introduced in concrete. By using this Hypo Sludge as a partial replacement of cement we can reduce the quantity of unused paper mill waste. Hypo Sludge is a new trend amongst other cementitious constituents. It was initially produced as artificial pozzolana for manufacturing paper since the countless waste come out from numerous processes of paper production[2]. Meanwhile, the price of cement was also gradually increasing every day. Hence, there was a necessity to incorporate industrial hypo sludge waste products in a suitable method to decrease price and pollution problems[3]. Hypo Sludge consists of little calcium and more calcium chloride. Thus, hypo sludge acts as cement because of the contents such as alumina, silica, magnesium and lime. The magnesium and silica enhance the property of setting time of the concrete. It also contains china clay, calcium carbonate, residual chemicals and cellulose fibers mixed with water.

Hypo Sludge adds advantageous properties to the concrete and helps to maintain low-cost. Numerous researchers have concentrated on the application of hypo sludge in concrete and cement production to achieve ecological conservation. Many studies have been carried out to check for the feasibility of implementing the hypo sludge in concrete production as fractional replacement of cement. The usage of hypo sludge in concrete can reduce the paper industry waste removal costs and thus develop a green concrete for the structure[4]. Paper mill waste replacement in cement was found to be thermally resistant and it was observed that it is more economical than the fly ash brick and ferrocement houses[5].

Balwaik et al. (2011) made a study on the application of paper mill waste in cement[6]. In his study, he used 5%, 10%, 15% and 20% replacement of paper mill waste in cement. The study was done on M20 and M30 concrete mix. The compressive strength, flexural and split tensile strength showed increase in strength of 10% on addition of paper mill waste, but the strength decreased as the content of paper mill waste percentage increased. Pitroda et al (2013) made an experimental study on 10%, 20%, 30% and 40% paper mill waste in cement[7]. The concrete mix M-25 and M-40 was used for the research. The compressive strength was tested for 28 days and 56 days. Paper mill waste of 10% in cement showed good increase in strength compared to other replacement percentages.

This study mainly focuses on the use of hypo sludge paper mill waste as a partial replacement of cement. The rate analysis was also done in order to show the cost effectiveness of the usage of waste and effective material in concrete. Usage of paper mill waste also reduces the carbon dioxide emission into the atmosphere, thus reducing the production of cement. Further, the quadratic polynomial equation was also developed.

2 Experimental Studies

In this research, Ordinary Portland Cement (OPC) of 53 grade, coarse aggregate, fine aggregate and super plasticizer were used. Hypo sludge from the Seshasayee paper and Boards limited, Erode was collected and used. Hypo sludge was used in the constituents of 20%, 30%, 40% and 50% as replacement in cement. Mix design was done for M30 according to IS 10262[8]. The physical properties were tested for the materials which are shown in Table 1.

Table 1. Property of the materials used

Sl.No	Material	Properties	Value
1	Cement	Specific Gravity	3.15
2	Fine Aggregate	Specific Gravity	2.66
3	Fine Aggregate	Grading of sand	Zone III
4	Coarse Aggregate	Specific Gravity	2.94

Hypo Sludge has more alike elements of cement such as lime, silica, alumina, magnesium, etc. The comparison between the properties of cement and hypo sludge[9] are shown in Table 2.

Table 2. Comparison of cement and Hypo Sludge[6]

Sl.No	Constituent	Cement (%)	Hypo Sludge (%)
1	Lime	62.00	46.20
2	Silica	22.00	9.00
3	Alumina	5.00	3.60
4	Magnesium	1.00	3.00

When hypo sludge is partially replaced in cement, the initial and final setting time varies according to the percentage replaced. Initial and final setting time was done according to IS 4031(Part 5):1988[10]. Table 3 shows the setting time (initial

and final) when there is a variation in hypo sludge replacement proportion.

Table 3. Setting time variation

Sl.No	Constituents	Initial setting time (min)	Final setting time (min)
1	Cement with 0% hypo sludge	31	602
2	Cement with 20% hypo sludge	32	599
3	Cement with 30% hypo sludge	33	598
4	Cement with 40% hypo sludge	34	596
5	Cement with 50% hypo sludge	35	595

3 Results and Discussion

Compressive strength was done according to IS 516 (1959)[11]. The cube specimens were casted in 100 x 100 mm mould. The 7 days and 28 days strength were tested. The compressive strength test was done for 20%, 30%, 40% and 50% of hypo sludge replacement of cement. The compressive strength was calculated using the equation:

$f_{ck} = \frac{P}{A}$ (eq.1)

Where, f_{ck} is the compressive strength of concrete, P is the compressive load and A is the cross sectional area.

The 7 days compressive strength were 22.60 MPa, 26.40 MPa, 21.80 MPa, 19.90 MPa and 16.20 MPa for 0%, 20%, 30%, 40% and 50% of hypo sludge replacement of cement respectively. The 28 days compressive strength were 34.80 MPa, 36.20 MPa, 32.40 MPa, 28.90 MPa and 26.40 MPa for 0%, 20%, 30%, 40% and 50% of hypo sludge replacement of cement respectively. Figure 1 shows the 7 days compressive strength and Figure 2 shows 28 days compressive strength results.

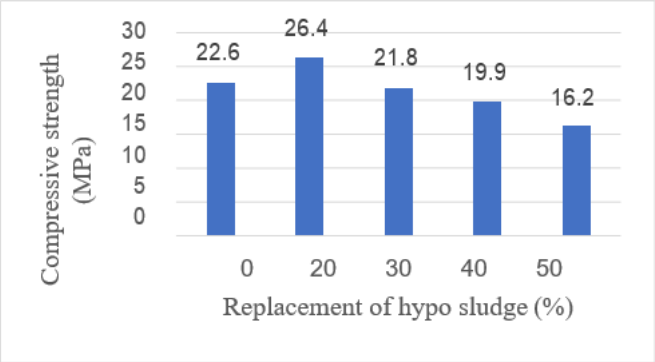

Fig 1. Compressive strength for 7 days

Cost analysis was performed for the partial replacement of hypo sludge in concrete. Rate analysis for partially replaced hypo sludge in cement was illustrated in Table 4.

Table 4. Rate analysis for partially replaced hypo sludge in cement

Cement (Kg/m3)	Cement cost (Rs)	Hypo sludge (%)	Hypo Sludge (Kg/m3)	Hypo sludge Cost (Rs)	Total cost (Rs)
320	2048	0	0	0	2048
256	1638	20	64	32	1670
224	1433	30	96	48	1481
192	1228	40	128	64	1352
160	1024	50	160	80	1104

Cost of cement per bag (50 Kg) = Rs.320.00. Cost of cement per kg = Rs. 6.40.
Price of hypo-sludge per kg = Rs.0.50. Cost of cement per m3 = Rs.320.

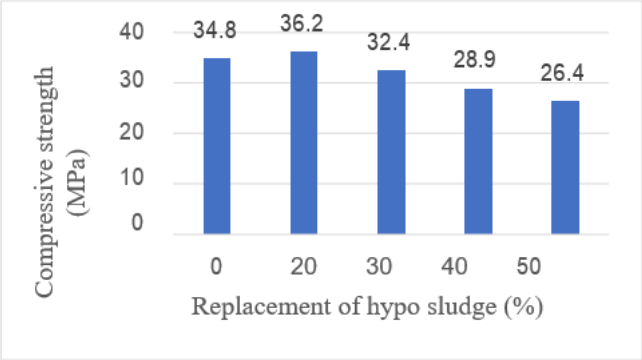

Fig 2. Compressive strength for 28 days

Cost fine aggregate per m3 = Rs. 764.00. Cost fine aggregate per m3 = Rs. 1260.00.

The prediction model was developed using the quadratic response surface equation which is as follows:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i<j}^{k} \beta_{ij} X_i X_j + e(X_i, X_i \ldots X_i) \quad (2)$$

Where y signifies response or target function, X_i signifies the independent variable, β_i, β_{ii}, β_{ij} signifies the coefficients of regressions for the first, second and cross degrees, and k signifies the factor of an effective amount and e indicates the error [8]. In this study, the compressive strength (f_{ck}) was preferred as the responses. Hypo sludge replacement (A) and curing age (B) were considered as the factors influencing the responses [12].

The quadratic polynomial equation has been proposed for the compressive strength using RSM:

f_{ck} = 9.89+(0.35xA) +(2.22xB) -(1.90x10^{-3}xAxB) - (9.50x10-3xA2) -(0.04xB2) (eq.3)

'f_{ck}''A''B'the curing days in nos. Figure 3 shows the normal plot of residuals for the compressive strength, in which all the data stay in the same linear line. Figure 4 shows the predicted vs. actual for the compressive strength, in which the data are arranged in a linear pattern. The graphs mentioned show the accuracy of the model and analysis done, though there is some minor deviation in the linear pattern, it can be used to predict the compressive strength of the concrete. Figure 5 shows the 3-D chart for the compressive strength of the concrete. Figure 6 shows the contour chart for the compressive strength.

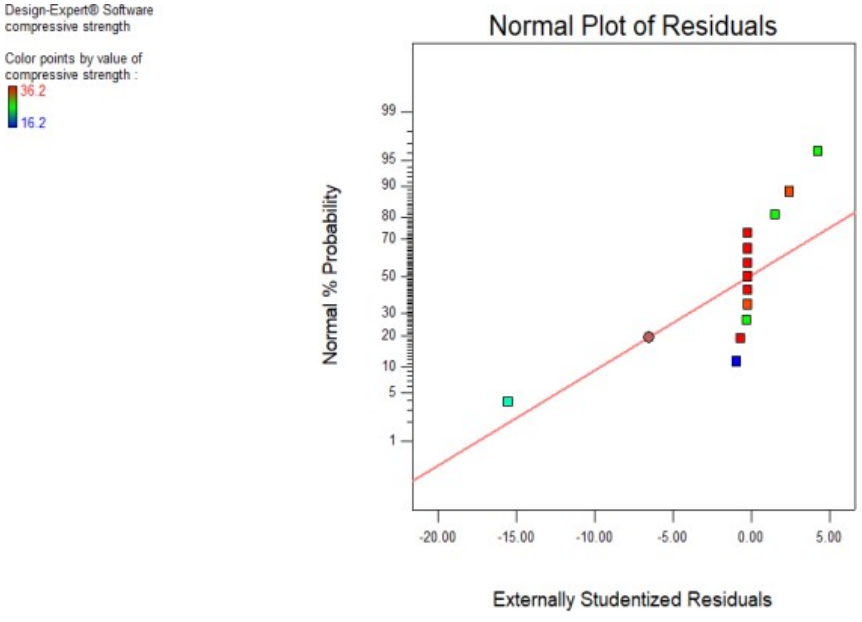

Fig 3. Normal plot of residualsfor the compressive strength

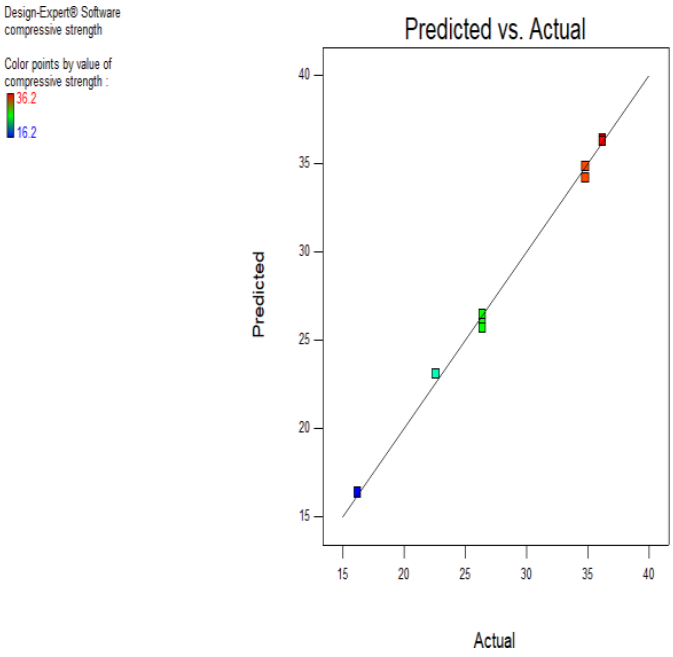

Fig 4. Predicted vs. actual for the compressive strength

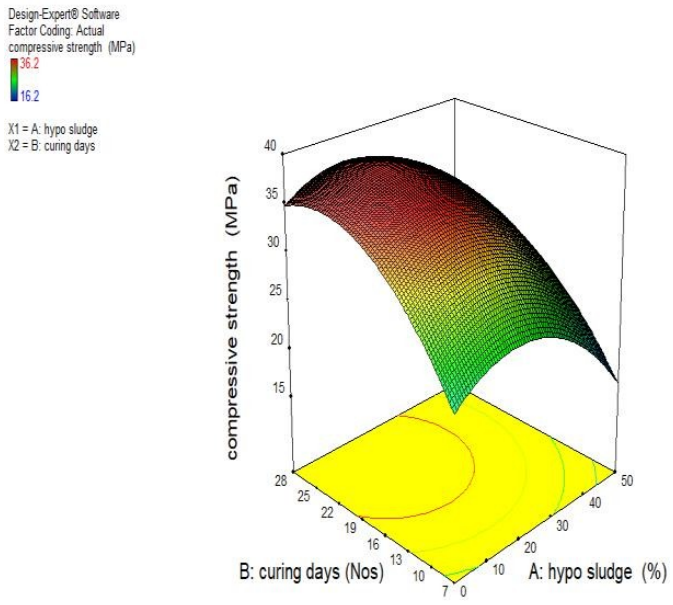

Fig 5. 3-D chart for the compressive strength.

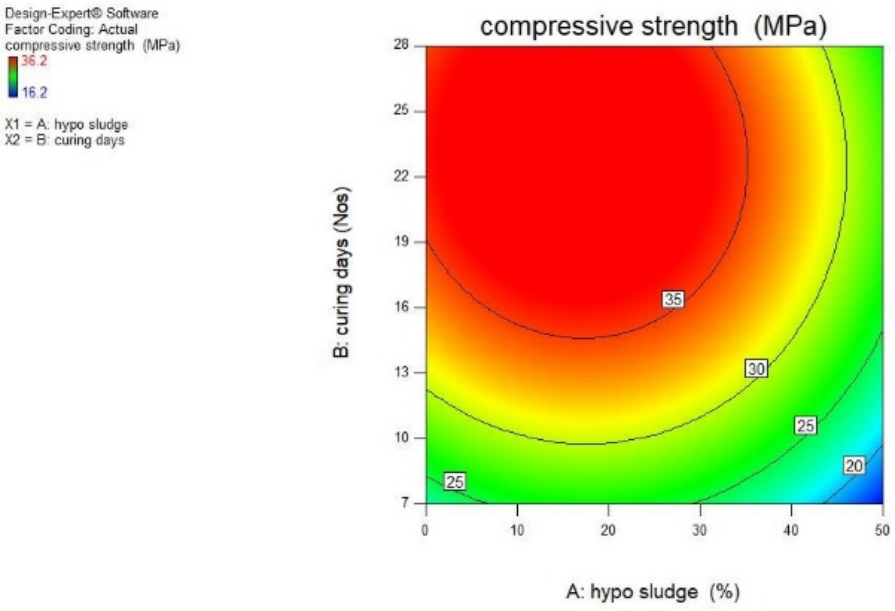

Fig 6. Contour chart for the compressive strength.

4 Conclusions

Based on the concrete compressive strength experimental study, the subsequent annotations are made concerning the resistance of partly replaced hypo-sludge. In this study, maximum compressive strength was found at 20% replacement of hypo- sludge in cement. The compressive strength starts decreasing at 30% and above. Thus, in this study, 20% replacement of hypo-sludge in cement were found to be efficient compared to other proportions. The cost of 20% replacement of hypo sludge in cement (kg/m3) is Rs. 1670.00, whereas for normal cement (kg/m3) is Rs. 2048.00. Environmental effects from wastes and the maximum amount of cement manufacturing are reduced through this study. In this study, the quadratic polynomial equation has also been proposed.

Cement production creates a lot of pollution problems and unwanted environmental hazards, which in turn affects mankind. In order to reduce the pollution problems, the production of cement has to be reduced. This study thus aimed at reducing the production of Cement. Hypo sludge from Paper mill industry has more similar properties to Cement. Thus, it has been utilized as replacement material in Cement. In this study, 20%, 30%, 40% and 50% of cement using hypo sludge was done. The cost analysis study was also been done for the same. Among which, 20% replacement of hypo sludge in cement was found effective in strength. When the percentage variation exceeds 20%, there is strength reduction. Hence, it is efficient to replace hypo sludge of up to 20% into cement.

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