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Effect of low cost fillers on cement hydration

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HIGHLIGHTS

- Compressive strength similar to OPC was obtained by replacing cement with coarser materials.
- Improved cement hydration rate due to more nucleation sites and autocatalytic effect of seeds.
- Using hydrated cement as fillers gives similar compressive strength while reducing the cost.

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ABSTRACT

The beneficial use of industrial, construction & demolition waste would solve the severe problem of their disposal being faced today. This study aims to overcome this challenge by utilizing these wastes in concrete as fillers and seeds to enhance strength and accelerate hydration. The compressive strength and rate of hydration of blends with partial replacement of cement by fillers; marble dust, rutile; and crushed hydrated cement seeds were studied. The results revealed the effectiveness of marble dust as a filler improving both compressive strength and rate of strength gain. The cement seeds proved to be effective with even at low replacement levels leading to equivalent strength and hydration rate of both pure and fly ash blended cements.

1. Introduction

Currently, global solid waste generation level is approximately 1.3 billion tonnes per year, which is expected to increase to 2.2 billion tonnes by 2025 because of increased demand and continuous development [1]. Overconsumption and inefficient use of materials are two of the prime reasons for the increased waste generation. The waste produced is mainly a by-product of construction, mining, agricultural, municipal & industrial processes [2,3]. In the absence of availability of proper disposal methods the waste generated is released into the nearby environment creating health and environmental issues. Various economic, social and environmental restraints identification of suitable disposal method remains a top priority. A viable alternative is to utilize these readily available waste materials as additives in concrete to improve properties as well as reduce the clinker content in concrete.

Replacement of Ordinary Portland Cement (OPC) by fillers helps to reduce the environmental burden, by reducing the amount of cement used. In European countries, use of limestone powder as fillers is a common practice. Along with economic and ecological benefits, it helps in increasing early age strength by improving the hydration rate of cement phases and reducing bleeding [4]. Numerous studies have been carried out on the effect of fillers on different performance parameters of concrete. The addition of fillers can affect the physical characteristics of concrete by improving the compactness of concrete, by enhancing hydration by acting as nucleation sites and reacting with components in the cement [5]. It has been noted that fillers, irrespective of their chemical composition, increase the early age strength primarily due to enhanced reaction rate [6]. Soroka et al. studied the effect of different fillers with different fineness and replacement percentages. Higher strengths were obtained for mortars containing fillers as compared to control mix [7]. Addition of fillers helps in reducing the size of pores and reduces the permeability of concrete [8]. In the long term this improves the durability of concrete.

Studies show that C-S-H added to cement mixes accelerates hydration. In this study the C-S-H in prehydrated cement is attempted to be used as seeds. The effect of seeding in hydration kinetics of cement has been investigated by researchers. The results indicate that prehydrated C_3S seeds (CSH gel) acts as a catalyst to C_3S hydration. Thomas et al. found by addition of relatively small amount of CSH to cement causes a significant change in the occurrence of main hydration peak, reduced induction period and

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amount of hydration occurring during early hours is increased. This effect could be attributed to additional nucleation sites being created through the hydrated cement grains [9]. Studies carried out by Hubler et al. suggested that the rate of reaction of blended cements can be adjusted to match Portland cement by adding seeds in the system [10]. This method is more economical as compared to additional grinding to achieve higher fineness, hence, the same rate of hydration.

Marble dust has been identified as fine filler for concrete in the construction industry. Studies have shown that on replacing cement with up to 10% marble dust does not affect the properties of concrete [11,12]. As the particle size distribution of marble dust is similar to that of cement, it provides effective nucleation sites during cement hydration for CSH gel to form. It has been reported that, for all non-pozzolanic fillers, the improvement in strength is similar [13,14].

The main objective of the present work is to study the effect of various waste products such as fillers on cement hydration. The work utilized marble dust (MD), white seeds (WC), OPC seeds and Rutile (RT) for this purpose. Rutile is used as a baseline in this study, since it has been widely used as a filler in literature. The effect of fillers on cement blended with Fly-Ash was also studied. Effect of agglomeration of fillers on mechanical properties has been studied.

2. Materials

OPC and white cements complying with IS: 12269-1987 was used in all the experiments carried out here. Fly Ash was procured from National Thermal Power Corporation, power plant at Dadri, Uttar-Pradesh and was used after sieving through 150 μm sieve. Rutile used in the study was of an industrial grade. Quartzitic sand with standard grading as prescribed in IS 650-1991 was used for the preparation of mortar. Tap water was used for all the experiments carried out in the study. In this study, two types of materials, i.e. fillers and seeds have been studied. Largely unreacted natural materials in fine powder form are called fillers here. Hydrated cements, with a significant quantity of CSH and crushed to fineness similar to cement are called seeds here. The chemical analysis of all the constituent materials is shown in Table 1. The relatively high LOI in the white cement generally indicates the presence of limestone as a filler in the cement. Two types of seeds were prepared using white cement (WS) and OPC (OS). This was done by casting cement paste specimens of 5 × 5 × 5 cm^3 of white cement and OPC at a constant water to binder ratio of 0.5. The specimens were cured in water maintained at 27 ± 2 °C for 42 days. The high water to binder ratio and prolonged curing were adopted with the aim to achieve almost complete hydration of the alite and phase in the cements. After curing, the specimens were dried and ground first by using mortar and pestle, thereafter further pulverised in a pulveriser to a fine powder. The powder was sieved through a 45 μm sieve to obtain the fine seeds. The specific gravity of the constituent materials was measured using *Le Chatelier's flask* method in accordance with the procedure described in IS 2720 Part 3. The specific surface area of the materials was determined using Blaine's air permeability method. The value of specific gravities and specific surface areas of the constituent materials are given in Table 2.

Table 1
Chemical analysis results.

S. No	Constituents %	Sample				
		OPC	Fly ash	Marble dust	Rutile	White cement
1.	Loss on ignition LOI	1.13	1.11	44.26	0.36	4.34
2.	Silica SiO_2	21.89	58.82	0.61	2.06	22.01
3.	Iron Fe_2O_3	3.79	6.19	0.58	0.10	0.39
4.	Aluminium Al_2O_3	6.91	30.62	0.28	1.95	3.79
5.	Calcium CaO	61.33	1.01	30.41	Traces	62.95
6.	Magnesium MgO	1.77	0.41	21.67	Traces	2.15
7.	Titanium TiO_2	–	–	–	95.02	0.01
8.	Sulphate SO_3	1.61	0.12	–	Traces	3.19
9.	Sodium Na_2O	0.51	0.19	0.08	0.06	0.29
10.	Potassium K_2O	0.54	1.30	0.03	–	0.46

Table 2
Physical properties of constituent materials.

	Blaine surface area (m^2/kg)	Specific gravity
Cement	316.7	3.18
Fly ash	551	2.7
Marble dust	238.3	2.87
Rutile	305.3	4.22
OPC seeds	275.4	2.3
White cement seeds	252.1	2.27

3. Methodology

Quartzitic sand with standard grading as prescribed in IS 650-1991 was used for mortar preparation at a fixed aggregate to powder ratio 3:1. An important factor to be considered when mixing two or more fines is ensuring proper dispersion of all particles to prevent agglomeration. To avoid agglomeration of the fine fillers were dispersed in water properly by using Poly-Carboxylate Ether (PCE) based dispersant, before mixing. 20 mortar specimens of size of 7.06 × 7.06 × 7.06 cm^3 were cast for compressive strength measurement for each blend. These were cured under water at 27 ± 2 °C and tested after 1, 3, 7, 14 and 28 days. Paste samples,

Table 3
Experimental matrix.

Sr. No	Notation	OPC	FLY ASH	WATER	SAND	FILLER Percentage	
1.	BASE	100	0	40	300	0	NONE
2.	MD01	99	0	40	300	1	MARBLE
3.	MD02	98	0	40	300	2	DUST
4.	MD05	95	0	40	300	5	
5.	MD10	90	0	40	300	10	
6.	RT01	99	0	40	300	1	RUTILE
7.	RT02	98	0	40	300	2	
8.	RT05	95	0	40	300	5	
9.	RT10	90	0	40	300	10	
10	WS0.1	99.9	0	40	300	0.1	WHITE
11.	WS0.2	99.8	0	40	300	0.2	SEEDS
12.	WS0.5	99.5	0	40	300	0.5	
13.	WS1.0	99	0	40	300	1.0	
14.	WS2.5	97.5	0	40	300	2.5	
15	OS0.1	99.9	0	40	300	0.1	OPC SEEDS
16.	OS0.2	99.8	0	40	300	0.2	
17.	OS0.5	99.5	0	40	300	0.5	
18.	OS1.0	99	0	40	300	1.0	
19.	OS2.5	97.5	0	40	300	2.5	
20.	FA35	65	35	40	300	0	NONE
21.	FWS0.1	64.935	34.965	40	300	0.1	WHITE
22.	FWS0.2	64.87	34.93	40	300	0.2	SEEDS
23.	FWS0.5	64.675	34.825	40	300	0.5	
24.	FWS1.0	64.35	34.65	40	300	1.0	
25.	FWS2.5	63.375	34.125	40	300	2.5	
26.	FWS5.0	61.75	34.125	40	300	5.0	
27.	FOS0.1	64.935	34.965	40	300	0.1	OPC SEEDS
28.	FOS0.2	64.87	34.93	40	300	0.2	
29.	FOS0.5	64.675	34.825	40	300	0.5	
30.	FOS1.0	64.35	34.65	40	300	1.0	
31.	FOS2.5	63.375	34.125	40	300	2.5	
32.	FOS5.0	61.75	33.25	40	300	5.0	