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Effect of nano-$CaCO_3$ on the physical properties of fly ash mortars

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Abstract

In this study, the effects of nano-$CaCO_3$ addition to mortars with fly ash at different rates on mortar properties were investigated. For this purpose, blended cement mixtures were prepared by using F class fly ash at 15%, 30% and 45% replacement level with CEM I 42.5 Portland cement in weight basis. A total of 12 different mortar compositions were prepared by adding nano-$CaCO_3$ at 1% and 2% by weight of the binder material in the mortar mixtures. In the preparation of the mortars, the water/binder ratio was kept constant as 0.5 and the sand/binder ratio was 3. The samples produced were kept in the curing pool at 21±1 °C for water curing until the 28th day; unit weight, water absorption and porosity tests were performed to examine the physical properties of the samples. As a result of the experimental studies, the addition of 1% and 2% nano-$CaCO_3$ was very useful in filling the voids in the mortar and significantly improved the physical properties of the mortars.

Introduction

The high rates of CO_2 emission and consumption of natural resources and energy in the cement production process bring some disadvantages. One of the solutions to this problem is to try to reduce the use of cement.

Fly ash, which is the industrial waste of thermal power plants that generates electricity, can be used in cement systems due to its physical and chemical properties and easy accessibility.

On the other hand, it is known that the use of mineral additives in the cement and concrete industry causes some performance losses such as late setting time and low early strength.

Nanotechnology is seen as one of the promising fields in order to solve the problems encountered as a result of increasing the use of mineral additives in cement-based materials. The use of nanoparticles, which are a product of nanotechnological developments and started to be used in many areas, in cement systems is a relatively new study subject, and there is no study in the literature examining the effects of nano-$CaCO_3$ addition on the strength and durability properties of mortars with fly ash at different rates.

Material and Method

Within the scope of experimental studies, CEM I 42.5 R Portland cement in accordance with TS EN 197-1 (2012) standard was used [1].

As seen in Table 1, fly ash contained more than 70% (SiO_2 + Al_2O_3 + Fe_2O_3) and less than 10% CaO. For this reason, fly ash used in this study was low lime F class fly ash according to ASTM C 618 (2014) standard [2], but siliceous V class fly ash according to TS EN 197-1 (2012) standard [1].

Nano-$CaCO_3$, which was used in experimental studies, was supplied as powdered commercial materials from Nanografi Nanotechnology A.Ş., a company based in METU Teknokent Ankara. The product properties and elemental analyze of nano-$CaCO_3$ are given in Table 2 and Table 3.

Table 1. Chemical and physical properties of the fly ash used

Chemical and Physical Properties	Results
SiO_2, %	55.94
Al_2O_3, %	19.85
Fe_2O_3, %	10.11
$SiO_2+Al_2O_3+Fe_2O_3$, %	85.9
CaO, %	4.78
Na_2O, %	1.20
SO_3, %	0.46
Cl^-, %	0.066
Free CaO, %	0.327
Ignition Loss, %	1.17
Particle Density, kg/m^3	2355
Activity Index, % (28 days)	78.45
Fineness, % (> 45μm)	13

Table 2. Product properties of nano-$CaCO_3$

Product Properties	Purity, %	Size, nm	Density, g/cm^3
Results	99.9	< 200	2.93

Table 3. Element analysis of nano-$CaCO_3$

Element Analysis, %	MgO	SiO_2	Al_2O_3	Fe_2O_3	Degree of Activity
Results	< 0.35	< 0.1	< 0.1	< 0.1	99.9

As mortar aggregate in experimental studies; CEN standard sand with a density of 2.56 g/cm^3 was used. Sand was produced by Limak Çimento Sanayi ve Tic. A.Ş. in accordance with TS EN 196-1 (2016) standard in 1350 g packages in Trakya Cement Factory [3].

A high rate of water reducer and superplasticizer in accordance with TS EN 934-2 (2013) standard was used in the mixtures [4]. It is recommended to use 0.20 – 2.50 kg additives for 100 kg cement in the product data sheet.

Table 4 shows 12 different cement groups studied.

Table 4. 12 different cement groups studied

Group No.	Notation	Content
1	OPC	100% Portland Cement
2	OPC-1NC	OPC + 1% Nano-$CaCO_3$
3	OPC-2NC	OPC + 2% Nano-$CaCO_3$
4	15FA	15% Fly Ash + 85% OPC
5	30FA	30% Fly Ash + 70% OPC
6	45FA	45% Fly Ash + 55% OPC
7	15FA-1NC	(15% Fly Ash + 85% OPC) + 1% Nano-$CaCO_3$
8	30FA-1NC	(30% Fly Ash + 70% OPC) + 1% Nano-$CaCO_3$
9	45FA-1NC	(45% Fly Ash + 55% OPC) + 1% Nano-$CaCO_3$
10	15FA-2NC	(15% Fly Ash + 85% OPC) + 2% Nano-$CaCO_3$
11	30FA-2NC	(30% Fly Ash + 70% OPC) + 2% Nano-$CaCO_3$
12	45FA-2NC	(45% Fly Ash + 55% OPC) + 2% Nano-$CaCO_3$

The unit weight test was carried out on prismatic mortar samples measuring 40x40x160 mm. The 28-day-old samples, which were left to dry in an oven at 100 °C for one day, were weighed on a precision scale, and their unit volume weights were found by dividing their geometric dimensions.

The water absorption and porosity tests were carried out on 28-day-old prismatic samples with the dimensions of 40x40x160 mm and a water/binder ratio of 0.5. The samples, which were saturated with water in the curing pool at 21±1 °C, were weighed with the help of Archimedes balance. With this method, the weights of the samples in the water were determined, their outer surfaces were dried and their saturated surface dry weights were determined. The dry weights of the samples, which were kept in a laboratory oven at 100 °C for one day, were determined. Finally, the water absorption and porosity ratios of the samples were calculated.

Results and Discussion

When the unit weight test results in Table 5 are examined, nano-$CaCO_3$ reduced the values in all groups. It was observed that this situation was caused by the density difference between the cement and the nanoparticles.

Table 5. Unit weight test results

Group No.	Notation	Unit Weight (kg/m^3) 28th day
1	OPC	2095
2	OPC-1NC	2030
3	OPC-2NC	2003
4	15FA	2078
5	30FA	2050
6	45FA	2005
7	15FA-1NC	2033
8	30FA-1NC	2027
9	45FA-1NC	1994
10	15FA-2NC	2018
11	30FA-2NC	2007
12	45FA-2NC	1988

Looking at the data in Table 6, nano-$CaCO_3$ reduced the porosity of the mortars and thus the water absorption. This situation also shows us that nanoparticles have a potential as a space filling material.

Table 6. Water absorption and porosity test results

Group No.	Notation	Water Absorption, % 28th day	Porosity, % 28th day
1	OPC	8.77	17.41
2	OPC-1NC	8.55	17.32
3	OPC-2NC	8.38	16.89
4	15FA	8.39	16.89
5	30FA	8.00	16.51
6	45FA	7.95	16.34
7	15FA-1NC	8.29	16.54
8	30FA-1NC	7.94	16.02
9	45FA-1NC	7.84	15.89
10	15FA-2NC	8.14	15.94
11	30FA-2NC	7.88	15.84
12	45FA-2NC	7.83	15.43

Conclusion

Unit weight test results showed that nano-$CaCO_3$ addition decreased unit weight values in all mortars. As the nano-$CaCO_3$ addition increased, the decrease in unit weight values continued. The addition of nano-$CaCO_3$ decreased the water absorption and porosity ratios in all mortar groups. As the nano-$CaCO_3$ addition increased, its contribution to the decrease in water absorption and porosity continued.

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