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Influence of Nano Materials Addition as Partial Replacement of Cement in the Properties of Concrete Pavement

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Abstract

The reduction of environmental impact of production and usage of cement is achieved through the reduction of clinker content in concrete by partial replacement of cement with Nano additives. In this investigation, the partial replacement of cement with coal fly ash class F, limestone dust and iron fillings was examined. The effects of such Nano fillers on early-age properties of concrete were measured and compared. Typical combined gradation of aggregates with maximum size of 19 mm which is usually used for of concrete for rigid pavement construction was implemented, the ordinary Portland cement content was 300 kg/m^3 and the water / cement ratio was 0.45. Three types of Nano materials (limestone dust, coal fly ash and iron filling) with 75 micron of maximum size have been implemented. Beam specimens of (280 x 70 x 70) mm size were prepared in the laboratory, cured for seven days, and then tested for water absorption and flexural strength. Such properties are considered essential for rigid pavement quality. It was concluded that the addition of coal fly ash or limestone dust in the range of (2-6)% as partial replacement of cement exhibit significant reduction in flexural strength as compared to reference mix as the additive content increases, while the iron fillings shows improvement in the flexural strength. On the other hand, the addition of fly ash, limestone dust, or iron filling shows significant reduction in the water absorption properties of concrete.

Keywords

Absorption, Nano Materials, Concrete, Fly Ash, Limestone Dust, Iron Fillings, Flexural Strength

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1. Introduction

The production of Portland cement poses great impact on the environment, the reduction of cement content by replacement with Nano materials could reduce such impact. Nano materials are defined as engineered materials with a least one dimension in the range of 1-100nm, [1]. The Nano materials could have some pozzolanic action which increases the strength of concrete or could take a part in blocking the voids and increase the unite weight of concrete. Reactive fillers which include all supplementary cementitious materials like fly ash, silica fume, slag, react with the cement hydration products in the presence of lime and water to form supplementary calcium silicate hydrates (C-S-H), increasing the strength and durability of concrete relative to ordinary concrete, [2]. The value of Nano materials comes from the properties generated as particle size becomes smaller and the surface area to bulk ratio increases dramatically. Higher surface areas lead to a marked improvement in performance of materials used in various applications. The physical and chemical properties of Nano materials can be tuned to enable specific applications. These properties can be controlled synthetically to enhance strength, porosity, and surface area. Research has been done by [3] on the application of Nano particles in cement based materials (such as paste, mortar and concrete). It was concluded that the rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction. [4] have observed that the use of

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limestone as a replacement for cement, increases the consistency of mortar, it was stated that Limestone additions improves concrete consistency by reducing water demand, and if a low water-to-cement (w/c) concrete mix design is used, high limestone replacement levels can result in almost similar concrete performance as ordinary Portland cements mixes. Structures smaller than a length characteristic of a phenomenon exhibit new chemistry & physics in the 1 to 100 nm range, the Strength change with great potential, The addition of these nanoparticles to cement paste containing high volumes of fly ash concrete mortars resulted in an increase in compressive strength, and the abrasion resistance of concrete for pavement, [5]. Nano materials have been reported as beneficial additives to asphalt cement and asphalt concrete mixture, fly ash, silica fumes, and hydrated lime have proved its positive impact on strength and resistance to deformation of asphalt concrete, while it improves the surface free energy of asphalt cement to resist stripping, [6, 7, and 8]. Nano composites are produced by adding Nano-particles to a bulk material in order to improve the bulk material properties. Materials reduced to Nano-scale can suddenly show very different properties compared to what they exhibit on a macro-scale, enabling unique applications, [9]. Nano-cement particles can accelerate cement hydration due to their high activity. Similarly, the incorporation of Nano-particles can fill pores more effectively to enhance the overall strength and durability. Thus Nano-particles can lead to the production of a new generation of cement composites with enhanced strength, and durability, [10]. The effect of fine additives (limestone, silica fume, fly ash, pozzolan, Nano-silica fume) on the plastic viscosity of cement paste was investigated by [11], twenty-four paste samples were designed and produced. Those pastes consisted mainly of cement and specific proportions of one or two fine additives. Results showed that limestone (40%) can improve the rheological behaviour of cement pastes, and the synergy of limestone (20%) and fly ash (20%) can lead to higher packing density. An investigation conducted by [12] concluded that Cement replacement up to 7.5% with SF and up to 2% with NS, leads to increasing compressive strength, split tensile strength and flexural strength for concrete. As reported by [13], the basic concept behind using Nano material which are having large surface area is to improve compressive and flexural strength at early ages, improved hydration characteristics and reduced porosity and water absorption when compared with conventional cementitious materials. Nano materials can also pave the path to reduce the cement content in concrete than the conventional mixes while maintaining same strength characteristics, which will lead into the production of 'greener' concrete.

The objectives of this investigation are to study the impact of implementation of Nano materials (coal fly ash class F, limestone dust, and iron fillings) as partial replacement of Portland cement on early-age properties of concrete including flexural strength and water absorption potential. Such properties are considered essential for rigid pavement quality.

2. Materials and Methods

2.1. Portland Cement

Ordinary Portland cement type I was utilized in this investigation, the chemical composition of the cement is verified according to ASTM [14] and ISS [15] and presented in Table 1. The physical properties are illustrated in Table 2.

Table 1. Chemical composition of cement.

Compound		% by weight
Oxide composition	CaO	64.4
	SiO_2	21.1
	Al_2O_3	5.78
	Fe_2O_3	3.59
	SO_3	2.35
	MgO	1.52
	Loss on ignition	0.89
	Lime saturation factor	0.92
	Insoluble residue	0.34
Mineralogical composition	C_3S	50.8
	C_2S	22.3
	C_3A	9.25
	C_4AF	10.9

Table 2. Physical properties of cement.

Property	Test result	Test method
Fineness (m^2/kg)	269.5	ASTM C204
Initial setting time (Hours)	2.30	ASTM C191
Final setting time (hours)	4.15	
Soundness	0.19	ASTM C151
Compressive strength (3-days), MPa	14.96	ASTM C109
Compressive strength (7-days), MPa	20.80	

2.2. Coarse and Fine Aggregates

Crushed gravel with a nominal size of 19 mm brought from Nibaai region was used in this work. The aggregates were air dried and separated into different sizes. Fine aggregate (passing sieve No. 4) was obtained from Al-Ukhaider region and used in this work. Table 3 shows the physical properties of coarse and fine aggregates.

Table 3. Physical properties of aggregates.

Type of aggregates	Crushed Coarse aggregate	Silica sand Fine aggregates
Specific gravity	2.68	2.42
Absorption	1	3.31
Sulphate content SO_3 %	0.08	0.45

2.3. Iron Filling

The waste iron filling was obtained from several local workshops, it is normally generated in hundreds of tons from the ironsmith processes. It was sieved and the portion passing 75 micron was implemented in this investigation. The physical properties are listed in Table 4, while the chemical composition is shown in Table 5.

Table 4. Physical properties of Iron filling.

Properties	Test result
Fineness modulus	2.65
Specific gravity	4.5
Density Kg/m^3	1946
Colour	Black-grey

Table 5. Chemical composition of Iron filling.

Compound	% by weight	Test method
Fe_2O_3	93.2	Titration with potassium dichromate using disphel amine as indicator
Al_2O_3	< 0.03	Auto colour analyser

2.4. Coal Fly Ash

Fly ash was obtained from local market, it was sieved, and the portion passing sieve No. 200, (75 micron) was implemented in this investigation. Table 6. Shows its physical properties. The chemical composition is illustrated in Table 7.

Table 6. Physical properties of Coal fly ash.

Property	Specific gravity	Specific surface area (m^2/ kg)
100% passing sieve size (75) micron	2.645	650

Table 7. Chemical composition of coal fly ash class F.

Chemical composition	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Loss on ignition
%	61.9	2.6	28.8	0.8	0.3	0.8

2.5. Limestone Dust

Limestone dust is non-plastic filler produced by the lime factory at Karbala governorate, it was sieved, and the portion passing sieve No. 200 (75) micron) was implemented in this investigation. Table 8 shows its properties, while the chemical composition is listed in Table 9. Fig. 1. demonstrates the Nano materials implemented in this investigation.

Table 8. Physical properties of Limestone dust.

Property	Specific gravity	Specific surface area (m^2/ kg)
100% passing sieve size (75) micron	2.617	389

Table 9. Chemical composition of limestone dust.

Chemical composition	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Loss on ignition
%	0.74	0.19	0.5	64.23	1.17	29.94

Fig. 1. Nano materials implemented.

2.6. Preparation and Testing of Specimens

Dense gradation usually used for asphalt concrete (binder course) pavement in Iraq has been implemented for this investigation. The coarse and fine aggregates are oven dried, sieved to different sizes; and then the desired weight of each size of aggregate was combined to satisfy the requirements of gradation. The design combined gradation of aggregate shown in Table 10 is selected using of State Commission of Roads and Bridges SCRB [16] limitations.

Table 10. Combined aggregates gradation adopted.

Sieve size mm	19	12.5	9.5	4.75	2.36	0.3	0.075
Percent finer by weight	100	95	83	59	43	13	7

The cement content was fixed to 300 kg/m^3 which represents the typical requirement for rigid pavement construction in Iraq as per SCRB [16], while the water / cement ratio was 0.45 to satisfy the workability requirements of pavement construction. The Nano material additives were oven dried, added to the combined gradation and mixed, then the remaining weight of cement requirement was added after considering the deduction of the amount of its partial replacement. The Nano additives percentages added as partial replacement of cement were (0, 2, 4, and 6)% for each type. Finally tap water was added and the concrete was mixed for two minutes using mechanical drum mixer. The concrete was casted in the beam mold, tamped, levelled and left for 24 hours at laboratory environment of 20 ± 1ºC. Beam specimens were then withdrawn from the mold and immersed into the water bath and left for curing at 20 ± 1ºC for one week. Specimens were subjected to determination of its absorption potential, then tested for flexural strength. Fig. 2 presents part of the prepared beam specimens, while Fig. 3 shows the Flexural strength testing machine.

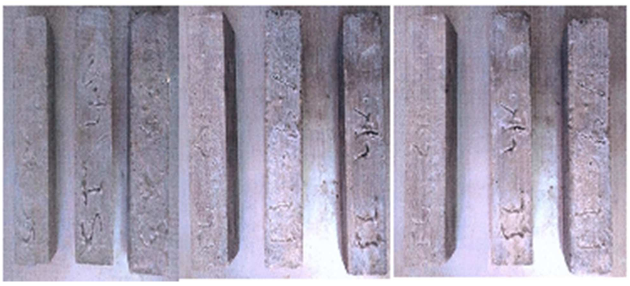

Fig. 2. Part of the prepared beam specimens.

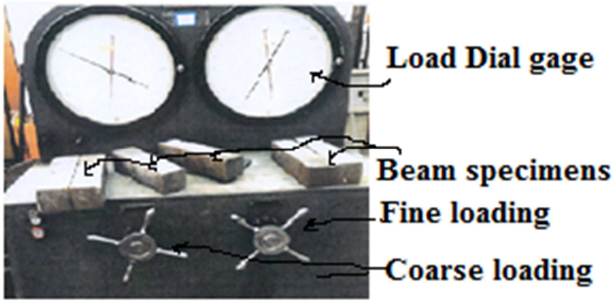

Fig. 3. Flexural strength testing machine.

3. Results and Discussion

3.1. Flexural Strength

The flexural strength test was carried out according to ASTM [17]. The flexural strength of (280×70×70 mm) beam specimens is determined by applying point load at one-third span over a length of (280 mm). Duplicate beam specimen were tested and the average results were considered. The flexural strength is then calculated by using equation (1).

$$Fr = \frac{P \times L}{b \times d2} \quad (1)$$

Where;

Fr = modulus of rupture, (MPa)

P= maximum applied load, (N)

L= span length, (mm)

d= depth of the specimens, (mm)

b= width of the specimens, (mm).

Table 11 demonstrates the impact of Nano materials on the properties of concrete. When limestone dust was implemented as partial replacement of Portland cement, marginal reactivity of limestone powder with cementitious minerals occurs and the flexural strength shows minimal reduction of (0.8 – 6.5)% as the percentage of replacement increases, such result is supported by [2] work, while implementation of coal fly ash exhibits significant reduction in the range of (6.5 – 12.7) in the flexural strength which is two folds as compared to limestone dust. This may be attributed to the fact that class F fly ash has low calcium oxide content (lime) as mentioned in Table 7, causing its pozzolanic action to be limited within the short curing period of one week. Similar finding was reported by [18] that Fly ash has low initial activity, but the pozzolanic activity significantly increased after long curing time. On the other hand, the addition of iron fillings had improved the flexural strength in the range of (2.8 – 4.8)% as compared to reference mix with no replacement of cement. This may be attributed to the solid nature of iron finning and its angular texture which accessed in blocking the voids and supporting the flexural strength. Such findings agrees well with [2] work. The acceptable limit of flexural strength for rigid pavement is 3.0 N/mm^2 as required by SCRB [16]. It may be summarised that the Nano additives implemented were able to replace up to 6% of Portland cement with minimal impact on the flexural strength, such impact will further be reduced as the curing time increases and the pozzolanic action proceeds.

3.2. Water Absorption Test

Table 11. Physical properties of concrete with Nano Additives.

Type of Nano additive	% of Nano additive	Flexural strength N /mm^2	% change in flexural strength	Water absorption %	% change in water absorption
Coal fly ash	0%	3.53	--	2.75	--
	2	3.30	- 6.5	2.65	- 3.6
	4	3.17	- 10.2	2.49	- 9.4
	6	3.08	- 12.7	2.44	- 11.3
Limestone dust	0%	3.53	---	2.75	--
	2	3.50	- 0.8	2.68	- 2.5
	4	3.40	- 3.6	2.50	- 9.0
	6	3.30	- 6.5	2.0	- 27.2
Iron fillings	0%	3.53	--	2.75	--
	2	3.63	+2.8	2.38	- 13.4
	4	3.67	+3.9	2.11	- 23.2
	6	3.70	+4.8	2.05	- 25.4

The water absorption was conducted according to ASTM [19], the water absorption test is carried out using (280×70×70 mm) beam specimens and equation (2), and the average water absorption of two samples was recorded and considered.

$$\text{Absorption after immersion}, \% = \frac{B-A}{A} \times 100 \quad (2)$$

Where:

A = mass of oven-dried sample in air, gm.

B = mass of saturated surface-dry sample in air after immersion, gm.

The Nano materials implemented in this work generally exhibits reduction in water absorption potential of concrete.

As presented in Table 11, the iron fillings shows the maximum reduction of water absorption in the range of (13 – 25)% for various percentages of iron fillings. On the other hand, the water absorption decreases as the coal fly ash and limestone dust percentages increases. The reduction in absorption potential may be attributed to the blocking of continuous voids and increment in the unite weight of concrete. Similar findings on reduction of permeability were reported by [3].

4. Conclusions

Based on the limited testing program, the following conclusions may be drawn:

1- The flexural strength shows minimal reduction of (0.8 – 6.5)% as the percentage of Nano additive increases when Limestone dust was implemented as partial replacement of Portland cement.

2- Implementation of coal fly ash as partial replacement of cement exhibits significant reduction in the flexural strength in the range of (6.5 – 12.7) which is two folds as compared to limestone dust.

3- Iron fillings had improved the flexural strength in the range of (2.8 – 4.8)% as compared to reference mix with no replacement of cement.

4- Nano additives implemented were able to replace up to 6% of Portland cement with minimal impact on the flexural strength, such impact will further be reduced as the curing time increases and the pozzolanic action proceeds.

5- The iron fillings shows the maximum reduction of water absorption in the range of (13 – 25)% for various percentages of iron fillings. On the other hand, the water absorption decreases as the coal fly ash and limestone dust percentages increases.

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