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Effect of Zinc Oxide, Silica and Kaolin on the Compressive Strength of Portland Cement Mortar

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Abstract— **This study aims to investigate the effect of adding Zinc oxide, Silica and Kaolin on the compressive strength of Portland cement mortar. The mix portion of mortar was prepared with a water to cement ratio of 1:2, cement to sand ratio of 1:2.5 and different percent of additives (0.2%, 5% and 10%). Results show that cement mortar, which did not contain Zinc Oxide (ZnO), increases the compressive strength (CS)of blended mortar. After 2 days, the best result was obtained for an additive of 5% Kaolin and 5% Silica with a 33.48% increase in compressive strength relative to the control. However, after 28 days the best result attained was for an additive of 5% micro silica with a 13.26 % increase in compressive strength relative to control. Addition of ZnO, in different particle sizes, resulted in negative effect on compressive strength contrary to some publications which indicate that the methods and blending ratio has significant effect in the CS. The molecular interaction, electron distribution and cohesion forces affect the CS.**

Index Terms— **Cement Mortar; Kaolin; Silica; Zinc oxide; Nanoparticles**

I. Introduction

The cement industry plays a significant role, in the rapid growth and development of infrastructure since it is a fundamental requirement of all constructions activities. Cement is used in housing, dams, bridges, industrial construction, and roads. It is also used for facades and other decorative features on buildings.

Moreover, the global cement industry contributes about 7% of greenhouse gas emission to the earth’s atmosphere [1]. Many additives have been used to improve cement mortar and concrete characteristics. Natural additives such as kaolin and silica which are a friendly environment option.

Kaolin is commonly used in the production of porcelain, paper filler, textiles, and medicines as absorbents. The white clay is resulting from the natural decay of feldspar. When pure or refined kaolin is heated, metakaolin is produced at a temperature of 600 to 850 ℃ (1112–1562 oF)[2]. It is a highly reactive pozzolan [3], but its physical and chemical properties rely primarily on the raw kaolin materials used, the calcination temperature, and the finish. The melting of calcined kaolin into concrete has been recorded in many cases, and metakaolin has been found to improve cement's compression strength.

Biljana Ilic [4] investigated the effects of metakaolin (MK) and activated kaolin (mechanically) on cement strength and microstructure under various curing conditions. Mortar mixtures were prepared Water–binder (w/b of 0.5) ordinary (age 2, 28 or 90 days) and autoclave cured. the following percentages (10%, 20%, and 30%) of ordinary Portland cement (OPC) was substituted with MK or activated kaolin (AK). The addition of Metakaolin enhances the compressive strength of ordinary-cured mortars. Because of the higher content of reactive silica, which intensely increased pozzolanic reaction, and due to the successful refining of their pore structure. MK may be used to replace OPC up to 30% of the time and have a positive impact on compressive power. Ordinary-cured mortars had lower strengths when OPC was replaced with AK, relative to all MK and reference mortars. Due to Higher specific surface area and finer AK particles were inadequate to compensate for the lower pozzolanic reaction and additional negative impact of the kaolinite involvement via the filler effect. The mortar with ten percent AK had the maximum compressive power (relative strength of 94 percent). In contrast to the reference, autoclaved MK and AK mortars had poorer compressive intensity due to the increased formation of hydrogarnet rather than tobermorite. The mortar with 10% AK had the maximum strength.

Many studies show that silica improves the comprehensive strength of cement [5-7]. Li et al. [8] examined the combined effects of micro and nano silica on the strength and microstructure of mortar. For cube strength measurement and microstructure imaging, mortar mixes with varying water, MS, and NS contents but a constant workability were developed. The results show that a very limited NS content of just 1–2 percent has significant positive effects on cube strength and microstructure, but a very strong need for superplasticizers. More particularly, combining MS and NS has strong synergistic effects on strength and microstructure. These results indicate that NS should not be added alone but should be applied along with MS to maximize their synergistic impact.

Zinc oxide (ZnO) is a white-inorganic powder that is water-insoluble. It an additive used in various applications, like lubricants, first-aid tapes, cosmetics, fire retardants, ferrites, rubbers, batteries, ceramics, plastics, paints, cement, adhesives, glass, etc. Reported research showed that Zinc oxide affects cement's compressive strength positively and

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negatively, depending on the products and methods used.
Olmo et al. [9] investigated the effect of metal oxides on cement properties such as unconfined compressive strength (UCS), setting time (ST), bulk density (BD), and noncombined water content (NCW). Four metal oxides were analyzed, which are commonly found in inorganic wastes from thermal processes: ZnO, Cr_2O_3, PbO, and Fe_2O_3. The percentages of these metal oxides in the formulations were chosen based on the composition of inorganic wastes from thermal processes: 0–30% dry wt. for Fe_2O_3, 0–15% dry wt. for ZnO, and 0–2.5% dry wt. for PbO and Cr2O3. The study of the experimental findings reveals that ZnO greatly retards the ST compared to cement; it also reduces the UCS of the final product at young ages, but its impact diminishes with sample age. At short sample ages, Fe_2O_3 has little effect on ST or UCS, but it reduces the product's UCS at short sample ages. Gopalakrishnan [10] investigated and evaluated the mechanical chemical, and physical properties of Ordinary Portland Cement (OPC) including zinc oxide nanoparticles. Mass percentage of Zinc oxide nanoparticles with ordinary Portland cement have been used as follow 0%, 1%, 2%, 3%, 4%, and 5%. The blend made with a water-binder ratio of 0.4 and a cement-sand ratio of 1:3 by weight. Compressive strength, setting time, flexural strength, porosity, water absorption, sulphate attack, electrical resistivity, and SEM analysis are performed on the prepared mortars. The zinc oxide nano particle setting time was significantly reduced, and the compressive strength was increased. Flexural strength findings demonstrate that cement mortars containing zinc oxide nanoparticles outperformed Portland cement mortar. The microstructure of the mortar containing zinc oxide nano particles shows that the nano zinc oxide particles significantly filled the pores, resulting in a reduction in the size of calcium hydroxide crystals and the formation of more hydration products.

II. Materials and Methods

A. *Materials*

The primary materials used in this study include (i) zinc oxide at different scale ZnO (bulk, micro and Nano (Klamar Company, China)), (ii) kaolin (river Nile), (iii) Portland cement (mass Cement Co., Sudan), (iv) silica the composition of silica is shown in Table 1. The average particle diameter for silica is <90 micrometer, for zinc oxide at micro scale is between 90-180 micrometer and for zinc oxide at nanoscale is (30±10) nm.

A. *Samples Preparation*

Compressive strength determinates on prismatic test specimens 40 mm x 40 mm x 160 mm in size. These specimens are cast from a batch of plastic mortar containing one part by mass of cement and three parts by mass of standard sand with a water-cement ratio of 0.50. The mortar is prepared by mechanical mixing and is compacted in a mould using a standard jolting apparatus. The specimens in the mould are stored in a moist atmosphere for 24 h and then the demoulded specimens are stored under water until strength testing at the required age.

Table 1: Composition of silica sample

Compound	%
Na_2O	0.454
MgO	0.241
Al_2O_3	1.777
SiO_2	96.770
K_2O	0.100
P_2O_5	0.010
SO_3	0.028
CaO	0.153
TiO_2	0.021
Cr_2O_3	0.049
MnO	0.008
Fe_2O_3	0.383
NiO	0.005
SrO	0.001
MoO_3	0.001

Table 2: Particle size distribution of the sand

Square mesh size [mm]	Cumulative sieve residue [%]
2.0	0
1.6	7±5
1.0	33±5
0.5	67±5
0.2	87±5
0.08	99±5

B. *Mortar Constituents*

Sand: It has a silica content of at least 98%. The moisture content is less than 0.2% expressed as percentage by mass of the dried sample. Its particle size distribution lies within the limits defined in Table 2. It also contained water, cements, and additives.

C. *Equipment*

Mixer consisted from stainless steel bowl with a capacity of about 5L and stainless blade has been used. Bowl was provided with means by which it is securely fixed to the mixer frame during mixing and by which the height of the bowl in relation to the blade and the gap between blade and bowl can be finely adjusted and fixed. The blade revolves about its own axis by an electric motor. The two directions of rotation were opposite and the ratio between two speeds was not a whole number. Mould consists of three horizontal compartments has been used. Three prismatic specimens 40 mm x 40 mm in cross section and 160 mm length were prepared simultaneously. A thin film of mould oil was applied to the internal faces of the mould.

D. *Method (A): Classical preparation method*

The mix proportion of traditional mortar and blended mortar were prepared with water to cement ratio of 1:2. The ratio of cement to sand was 1:2.5 based on constant cement weight 450 g and different percentage of additives (Nanoparticle zinc oxide, silica, kaolin) as shown in Table 3.

ZnO particles were mixed with water for 1 minute. Cement and sand were added and mixed at medium speed up to 3-4 min. The mortar was then filled into the lubricated standard mould. Other additives were added to cement and sand and then were mixed with water at medium speed up to 3-4 min then the mortar was filled into the lubricated standard mould. All samples had been cured in water tank for 2 and 28 days according to BS: 1990.

E. Method (B): Drying of Samples for three days Before Curing:

The mix proportion of mortar was prepared with water to cement ratio of 1:2. The ratio of cement to sand ratio was 1:2.5 based on constant cement weight of 450 g and different percentage of additives (Nanoparticle zinc oxide, silica, kaolin) as shown in Table 4.
ZnO particles (micro and Nano) were mixed with water for 1 minute. Cement and sand were added with this mixture and mixed at medium speed up to 3-4 min then mortar was filled into the lubricated standard mould. All samples had been dried for 3 days and cured in water tank for 2 and 28 days according to BS: 1990. Samples had been dried for 3 days before braking. Samples had been dried for 3 days before braking.

Table 3: Description of samples content in method (A)

Sample number	Additive percentage of total weight
S1	0% additives
S2	2.5% bulk zinc oxide
S3	5% bulk zinc oxide
S4	10 % bulk zinc oxide
S5	0.5% micro zinc oxide
S6	1% micro zinc oxide
S7	5% micro silica
S8	10% micro silica
S9	0.2 Nano zinc oxide
S10	0.2% Nano zinc oxide, 5% micro silica
S11	0.2% Nano zinc oxide, 10% micro silica
S12	5% Kaolin
S13	10% kaolin
S14	5% Kaolin and 5% silica

Table 4: Description of samples content in method (B)

Sample number	Additive percentage of total weight
B1	0.2 % Bulk zinc oxide
B2	0.2 % Micro zinc oxide
B3	0.5 % Micro zinc oxide
B4	0.2 % Nano zinc oxide
B5	0.2 % Nano zinc oxide, 5% silica
B6	0.2 % Nano zinc oxide, 10 % silica
B8	0.5% Nano zinc oxide

III. RESULTS AND DISCUSSION

For Classical preparation method (A). the results of compressive strength after 2 and 28 days are shown in Table 5 and Figure 1. Cement mortar which contained silica and kaolin but did not contain ZnO increased the compressive strength of the blended mortar. The highest result after 2 days was sample S14 (5% Kaolin and 5% silica) where the percentage increase by 33.478% relative to the control. The highest result after 28 days was sample S7 (5% micro silica) with a 13.26 % increase in compressive strength relative to the control. Cement mortar which contained ZnO Disintegrated in the curing tank, so the experiment was repeated for samples contained ZnO however after drying for three days before curing as shown in method B.

Results of compressive strength for method B (Drying of Samples for three days before curing are shown in Table 6 and Figure 2. Most samples containing zinc oxide did not Disintegrated except the sample containing 0.5% nanoparticle. However, it was noticed that ZnO reduces the compressive strength of samples contrary to work published Gopalakrishnan [10] and Nivethitha [11] which indicate that the ratio of the blend and the method used fro the same material significantly affect the properties of the comprehensive strength.

According to Arliguie and Grandet [12, 13], an amorphous layer of $Zn(OH)_2$ is created during the hydration of the C_3S phase in the existence of Zn, slowing the hydration of this phase. The amount of sulfate in the cement effects the hydration of C_3A phase in the presence of Zn. The hydration of C_3A is slowed when the sulfate concentration exceeds 2.5 percent.

By comparing the electron distribution of Zn which is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2$ with the electron distribution of Si and AL which are $1s^22s^22p^63s^23p^2$ and $1s^22s^22p^63s^23p^1$ respectively, it can be observed that the last orbital in the case of Zn is S which is already full, however, the last orbitals in the case of Si and AL are P which is not filled, this could be the reason about the reactivity of materials contain Si and Al in pozzolanic reaction. Moreover the molecular interaction could also play a catalytic role in pozzolanic reaction. By comparing the electronegativity of Zn,Si and Al, it can be noted that the highest electronegativity value is for Si then AL and at last Zn.
In term of oxidation number it can be observed that Si has the highest possibility of oxidation states, then Al and at the last Zn.

The negative effect on compressive strength is worse as zinc oxide particle size is reduced and this is due to the high surface area of nanomaterials. However, results for 0.2% nano zinc oxide and 5% silica, produced better results than the control which could be due to the high cohesion force of silica.

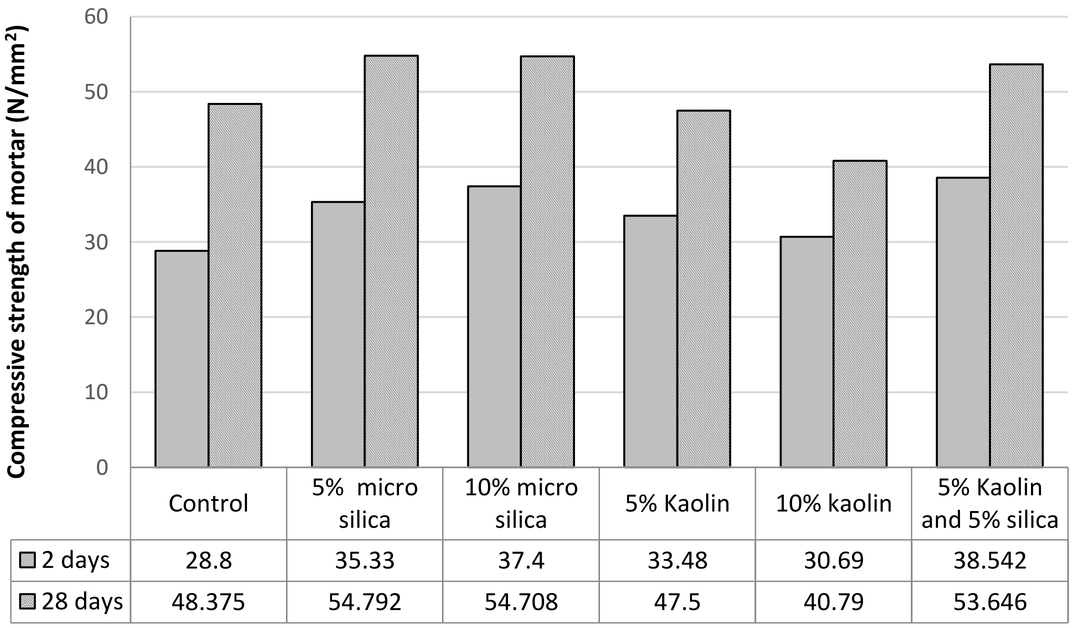

Figure 1: Comprehensive strength (N/mm2) results of method (A)

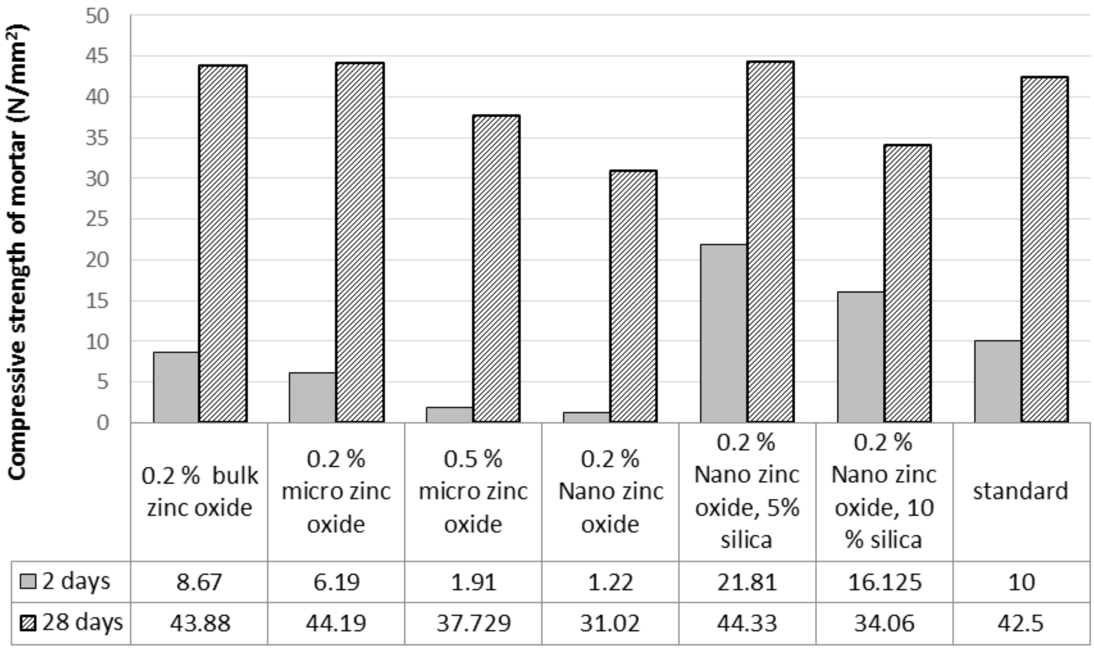

Figure 2: Comprehensive strength (N/mm2) result of method (B) where samples are dried for 3 days prior to curing

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Table 5: Compressive strength (N/mm2) result of method (A)

Sample number	Additive percentage of total weight	Compressive strength of mortar (N/mm2) after 2 days	Compressive strength of mortar (N/mm2) after 28 days
S1	0% additives	28.875	48.375
S2	2.5% bulk zinc oxide	Disintegrated	Disintegrated
S3	5% bulk zinc oxide	Disintegrated	Disintegrated
S4	10 % bulk zinc oxide	Disintegrated	Disintegrated
S5	0.5% micro zinc oxide	Disintegrated	Disintegrated
S6	1% micro zinc oxide	Disintegrated	Disintegrated
S7	5% micro silica	35.33	54.792
S8	10% micro silica	37.416	54.708
S9	0.2 Nano zinc oxide	Disintegrated	Disintegrated
S10	0.2% Nano zinc oxide, 5% micro silica	Disintegrated	Disintegrated
S11	0.2% Nano zinc oxide, 10 % micro silica	Disintegrated	Disintegrated
S12	5% Kaolin	33.48	47.5
S13	10% kaolin	30.69	40.7916
S14	5% Kaolin and 5% silica	38.542	53.646

Table 6: Compressive strength (N/mm2) result of method (B) where samples are dried for three days before curing.

Sample number	Additive percentage of total weight	Compressive strength of mortar (N/mm2) after 2 days	Compressive strength of mortar (N/mm2) after 28 days
B1	0.2 % bulk zinc oxide	8.67	43.88
B2	0.2 % micro zinc oxide	6.19	44.19
B3	0.5 % micro zinc oxide	1.91	37.729
B4	0.2 % Nano zinc oxide	1.22	31.02
B5	0.2 % Nano zinc oxide, 5% silica	21.81	44.33
B6	0.2 % Nano zinc oxide, 10 % silica	16.125	34.06
B8	0.5% Nano zinc oxide	Disintegrated	Disintegrated

IV. Conclusion

Cement mortar with silica and kaolin additives, however which did not contain ZnO, have a higher compressive strength of blended mortar. The highest result obtained after 2 days was for a sample containing 5% Kaolin and 5% silica which resulted in a 33.45% increase in compressive strength relative to the control. However, after 28 days the best results obtained was for the sample containing 5% micro silica which resulted in a 13.26% increase in compressive strength relative to the control. Further investigations into the effect of drying cement mortar which contains ZnO as an additive, prior to curing, still resulted in a negative result compared to the control which is in contrary to some publications. Which indicate that the method and the blend ratio of cement-water-ZnO has significant effect on the comprehensive strength of cement mortar. The molecular interaction, cohesion force and the electron distribution affect the properties of the comprehensive strength.

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