EFFECT OF MgO POWDER ON PHYSICAL AND MECHANICAL PROPERTIES OF POLYOLEFIN FIBER REINFORCED CONCRETE

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Abstract

Expansive additives are widely used to compensate the drying shrinkage of cement-based materials to avoid cracking. However, the expansion of conventional expansive additive depends strongly on wet curing and is mainly generated at early age, and hence it may not work well in concretes without sufficient water supply or exhibit long-term shrinkage. MgO-based expansive additive, for which less water is needed for the formation of Mg(OH)₂ in comparison to other expansive additives. For the purpose this paper proposed a new kind of cement concrete overlay material comprised of polyolefin fiber and MgO powder. An experimental test procedure including density, compressive strength and flexural strength in this article was investigated. The results showed improvement of all the properties of the concrete mixes. Obvious compound effect of polyolefin fiber and MgO powder on concrete properties was noticed.

Keywords: MgO, Expansive additive, polyolefin fiber, density, compressive strength and flexural strength.

1. Introduction

Excessive autogenous, drying, and thermal shrinkage of concrete elements can result in cracking. Various methods have been used to reduce shrinkage cracking in concrete, such as incorporation of fibers, shrinkage-compensating, shrinkage reducing admixtures (SRA), supplementary cementitious materials, and provision of sufficient internal curing. As a result, MgO powder admixtures based, have been developed that can be used as an addition or partial replacement of cement in concrete to compensate for shrinkage[2]. Magnesium oxide-based shrinkage-compensating concrete (MgO concrete) is concrete with an additive of MgO powder.

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The compensation for shrinkage was mainly due to the volume expansion caused by the hydration of expansion additives. The expansion of MgO concrete therefore closely matches the shrinkage of mass concrete as it cools, and the concrete has been of particular interest in construction of dams to minimize crack development, simplify temperature-control measures, and speed up construction[3][4].

Besides, fiber reinforcement has been shown to improve the ductility, toughness, flexural strength and shear strength of cementitious materials, to reduce shrinkage cracking and permeability and to enhance fatigue and impact resistance. Fiber reinforcement is used to improve the brittle nature of cementitious composites[5]. However, inside fiber reinforced concrete, especially in the interface transition zone (ITZ) between fiber and cement substrate, there tend to be a large quantity of harmful pores, giving rise to the weak bonding among cement hydrates, fibers and aggregates[1].

For the purpose of addressing these issues above, some researchers have conducted a series of tests and theory studies. A design idea that is fiber which has been put forward through their explorations[6].

2. Previous Studies

Arash S. Morteza A.(2017)[7] studied the utilization of polyolefin fibers in reinforced concrete. The objective of this research was to determine the mechanical properties of polyolefin fiber reinforced lightweight concrete (LWC). Compressive, flexural strengths of the sample were measured. Polyolefin fibers were added to the reinforced composite in variable amounts (0-2%). The results showed that the highest compressive strength was obtained in LWC containing 1% fiber led to an increase of about 8%. However, a reduction in compressive strength was observed when the amount of fiber was increased. Moreover, increasing the amount of fiber presented an enhances the strength properties of the concrete and in most cases it improves the efficiency of the fibers in the matrix structure of concrete. Addition of 1 and 1.5% fibers increased the flexural strength by 4.4% and 6%, respectively. Chenfei W. (2020)[8] investigated the influence of fiber volume content on the mechanical properties, durability, and chloride ion penetration of polypropylene fiber reinforced concrete in a chloride environment. Tests were carried out on polypropylene fiber reinforced concrete with polypropylene fiber contents ranging from 0% to 0.5%. Extensive data from flexural strength testing, dry–wet testing were recorded and analyzed. The test results show that the addition of the fiber improves the failure form of the concrete specimens, and 0.1% fiber content maximizes the compactness of the concrete. The flexural strength of specimen with 0.1% fiber shows the highest strength obtained herein after freeze–thaw cycling, and the water absorption of specimen is also the lowest after dry–wet cycling.

Zainb. H. M. (2018)[9] Examined the effect of adding MgO powder to the mixtures with ratios (1, 2, 3 and 4) % by weight of cement. The parameters of investigation included compressive strength, ultrasonic pulse velocity and absorption tests. Results showed that the best ratio when adding 2% MgO powder by weight of cement, where the rate of increase in compressive strength and ultrasonic pulse velocity at age 28 day were (148.76 and 59.57)% compared to the reference mixture.

For the purpose of addressing these issues above, this paper proposed a new kind of concrete comprised of MgO powder with polyolefin fibers and SBR latex. An experimental test
procedure including impact resistance and ultrasonic pulse velocity in this article was investigated. We focus on the flexibility and toughness of this type of concrete, in addition to its routine mechanical properties. Meanwhile, the modification mechanism of MgO powder with polyolefin fibers and SBR latex was as well explored quantitatively by SEM.

Kaijian H. et al.(2019)[10] investigated concrete mixtures with varying MgO powder contents were tested in the lab to evaluate the effect of MgO powder on concrete’s mechanical properties (compressive strength and flexural strength), volume change, and presence of micro cracking. The results indicate that the addition of MgO decreases concrete’s compressive strength (up to 27%), but a slight improvement (up to 12%) in flexural strength is achieved when the MgO content is limited to 8%. The field study shows that the volume expansion caused by MgO hydration can effectively compensate concrete shrinkage.

3. Materials and Experiments
3.1. Materials
Portland cement, MGO powder, coarse aggregates, fine aggregates, polyolefin fibers, and master glenium 51(MG-51) super plasticizer were used as the experimental objects. The details about each material are enumerated below.

3.2. Ordinary Portland Cement
The cement used in this study was Iraqi ordinary Portland cement, commercially known as (AL-Mass) and its fineness due to ASTM C204 –05 3914 cm²/g[11].The chemical and physical properties of OPC are given in Table (1)and (2) which adapted to IQS 5/1984[12].

| Chemical composition | Oxide composition | Item | Content% | Spec. Limit |
|----------------------|------------------|------|----------|-------------|
| Silica               | SiO₂             | 14.75|          | -           |
| Alumina              | Al₂O₃            | 3.149|          | -           |
| Iron oxide           | Fe₂O₃            | 2.857|          | -           |
| Lime                 | CaO              | 63.23|          | -           |
| Magnesia             | MgO              | 3.05 | ≤ 5%     |             |
| Sulphate             | SO₃              | 2.4  | ≤ 2.8%   |             |
| Loss on Ignition     | L.O.I.           | 3.04 | 4%       |             |
| Lime                 | L.S.F            | 0.95 | 0.66-    |             |
Table (2) Physical Properties of Portland Cement.

| Physical properties | Item                        | Test result | Spec. Limit |
|---------------------|-----------------------------|-------------|-------------|
|                     | Fineness(m²/kg)             | 391.4       | 230         |
|                     | Autoclave exp               | 0.24        | 0.8%        |
|                     | Compressive Strength (MPa)  |             |             |
|                     | 3-days age                  | 17.6        | 15.0        |
|                     | 7-days age                  | 26.0        | 23.0        |
|                     | Time of setting             |             |             |
|                     | Initial (min)               | 144min.     | 45min.      |
|                     | Final (min)                 | 396         | 10ax        |

3.3 Natural sand aggregate

The fine aggregate used in concrete mixes is brought from Ukhaidher area with maximum size 4.75mm. The grading of fine aggregate is shown in Table (3). The used sand is within zone (2) according to the requirements of IQS 45/1984[13]. Table (4) Chemical Properties of fine aggregate

Table (3) Grading of fine aggregate.

| Sieve No. | Sieve size (mm) | %Passing by Weight | Limit of Iraqi specification on No.45,1984 zone (2) |
|-----------|-----------------|--------------------|---------------------------------------------------|
| 1         | 10              | 100                | 100                                               |
| 2         | 4.75            | 95.50              | 90-100                                           |
| 3         | 2.36            | 78.70              | 75-100                                           |
| 4         | 1.18            | 74.60              | 55-90                                            |
| 5         | 0.60            | 52.60              | 35-59                                            |
| 6         | 0.30            | 12.40              | 8-30                                             |
| 7         | 0.15            | 2.30               | 0-10                                             |
| 8         | > 0.15          | 0                  | --                                               |

Table (4) Chemical Properties of fine aggregate.

| Specification | Result of test | IQS No.45 /1984 |
|---------------|----------------|-----------------|
Table (5) the physical and chemical properties coarse aggregate.

| Sieve size(mm) | % Passing by Weight | IQS NO. 45,(20-5)mm |
|----------------|---------------------|---------------------|
| 37.5           | 100                 | 100                 |
| 20             | 100                 | 95-100              |
| 14             | 91.20               | Not limited         |
| 10             | 63.35               | 30-60               |
| 5              | 2.3                 | 0-10                |
| 2.36           | 0                   | Not limited         |

Chemical Properties of gravel

| SO3 content % | Not more than 0.1% |
|---------------|--------------------|
| Finer than 0.75mm | Not more than 3% |

| Water adsorption % | Not more than 2% |
|--------------------|-------------------|

3.4 Natural gravel aggregate (NG)
The coarse aggregate used throughout this study is provided from Al-Nibaey region with maximum size of 20mm. The physical and chemical properties test due to IQS 45/198[13]. The results of test are shown in the Table (5).

3.5 Water
Ordinary tap water was used for all concrete mixes and also for curing. It has added in several stages to facilitate the mixing and homogeneity of materials (OPC, sand, gravel). For all mixtures the water to binder ratio was set at 0.34.

4.6 (Super Plasticizer)
Superplasticizer was used in this research as chemical additive to reduce the water in superior degree, which carries the trade name Master Glenium 51.

4.7 Magnesia powder (MgO)
Magnesium oxide powder (MgO) used in this study is light white magnesia. Figure (1) shows MgO powder. Its added to mixes with (1%, 3%,5%) ratio of cement weight. The table (6) shows the properties of MgO according to manufacturing company.

| Properties      | Value       |
|-----------------|-------------|
| Bulk density    | ~10 g/100ml |
| Water soluble matter | 2.0%       |
| Chloride(Cl)    | 0.15%       |
| Sulphate (SO4) | 0.5%        |
| Arsenic (As)    | 0.0003%     |
| Heavy metals (as Pb) | 0.002%   |
| Iron (Fe)       | 0.05%       |

Figure (1): magnesium oxide powder.

3.7 Polyolefin Fiber

The fibers used in this work with volume fraction (0.5%, 0.75%,1%) as show in figure (2). Technical properties of polyolefin fiber showed in table (7) according to manufacturing company.

| Chemical Base | Polyolefin          |
|---------------|---------------------|
| Appearance    | White, straight fibers |
### Table (8) Mix proportions of material used in this work.

| Mixes | Cement | Sand | Aggregate | Water L/m³ | SP By wt of | MgO By wt of | Fiber content | SBR By wt of |
|-------|--------|------|-----------|------------|-------------|--------------|--------------|-------------|

3.8 Materials proportion

This research included one mixture as follows: Mixing ratio (1:2.5:4) cement: sand: gravel and water to cement ratio of 0.34 (mixture of reference). The proportions of all mixes were presented in Table (10).

3.9 Casting and curing of test specimens

Mixing a dry material (sand with gravel) and cement mixed with magnesium oxide then add water or water mixed with superplasticizer according to the type of mixture and continue mixing for 4 minutes. Then the required amount of (water/admixture MG-51), mixing all the consistent for several minutes, finally mixes with different volume fractions of PO fibers are added slowly then mixing the mixture for very few minutes until getting the homogeneity of concrete mix.

After that casting mixture in molds cubic dimensions (100×100×100mm) for ultrasonic test and (150 mm ×70 mm) cylindrical concrete specimen (disk) for impact test, in two layers, and compact each layer on the vibrator device for 20 seconds.

After molding the specimens were kept for 24 hours in laboratory, at room temperature. Then the specimens were demolded and cured in tap water where they were kept until the testing time at the ages 28 days. Table (8) Mix proportions of material used in this work.

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**Figure (2): Polyolefin fiber.**
4. Test Procedures

A parametric study was carried out to investigate dynamic properties of concrete mixture of this work.

4.1 Hardened Density Test

100*100*100 mm concrete cubes were used for density test. The specimens were immersed in tap water for not less than 24 hours, and the immersed mass was determined. Then, the specimens were taken dried for not less than 24 hours, and then the dried mass was determined. This test was carried out according to ASTM C 642-13[14]. Density of specimens determined by dividing the unit weight of the specimen by the unit volume.

\[ \rho = \frac{W}{V} \]  

Where: \( \rho \) is density of the concrete specimen (kg/m³), \( W \) is the mass of specimen (kg), and \( V \) is the volume of specimen (m³). Mass will be measured with a sensitive digital balance, in (kg), and volume will be measured by multiplying its length, height, and width of specimen.

\[ V = l \times w \times h \]  

Where \( l \) is length (m), \( h \) is height (m), \( w \) is width (m).

Density can indicate defect in a product, such as a crack or a bubble in cast parts (known as voids) in the concrete specimen [15]. Density were calculated using the following equation:

\[ \rho = \frac{W}{V} \]  

Where \( \rho \): The density of concrete specimen (g/mm³), \( W \): mass (g), \( V \): volume of specimen (mm³).

4.2 Compressive strength test

15 concrete mixes were produced to test the compressive strength. Each of them was tested in three ages. The test was measured by using cubic specimens with 100x100x100 mm and measured according to BS 1881 Part1 16:1983 C109 by digital compression test device, which giving load in kN and the compressive strength in MPa. of 4000 kN capacity under load control, until the failure of sample occurs, as shown in the figure (4.9). The compressive strength test was determined according The compressive strength was calculated by:

\[ c = \frac{P}{A} \]  

\( F_c \): compressive strength in MPa
\( P \): maximum load in KN
A: Loaded surface area in mm²
All test procedures conform to B.S. 1881: part 116(1989)[16].

4.3 Flexural strength (Modulus of rupture)
Flexural strength of concrete was measured on (10×10×50) mm prism specimens according to ASTM C78/C78M[17]. The prisms were subjected to two-point loading. The loading is at a rate of 0.06 MPa/sec. The specimens are tested at ages of 7, 14 and 28 days. Span length, calculate the modulus of rupture as follows:

\[ R = \frac{PL}{bd^2} \]  
\[ \text{.......... (4-5)} \]

Where:
- \( R \) = modulus of rupture, MPa,
- \( P \) = maximum applied load indicated by the testing machine, N
- \( L \) = span length, mm
- \( b \) = average width of specimen, mm, at the fracture, and
- \( d \) = average depth of specimen, mm [in.], at the fracture[18].

5. Results and Discussions

5.1 Density Results

Figures (3) show increasing in density with the addition of polyolefin fiber from (0.5 to 0.75) \( V_F \) % of PO fibers increased. While the addition of PO fibers up to (1%) \( V_f \) cause reduction in density of concrete due to PO fiber tends to balling and cause air cavities which tend to decrease the density[19]. Figure (4) show that the density increased at mix contain (1% MgO +0.75 %PO) due the due expansion effect of the hydration product MgO(OH) which compensate the plastic shrinkage in concrete and the results was a reduction in capillary pores. Then at (3and 5)%\( W_f \) of MgO with 0.75% PO fibers the density was reduced due to excessive expansion MgO(OH)\(_2\) which effect diversely on the concrete density.

![Figure(3):Density of concrete polyolefin fibers.](image)
5.2 Compressive Strength

It was a test of compressive strength to its importance in the design of constructions as well as it gives an indication of most of the properties of concrete. Compressive strength of each sample was as shown in Figures (5) and (6). According to the experiment results of this work, compressive strength of samples 28 days was tested for three samples per design and compressive strength test results of concrete are shown in Figure (5). As it was shown in the figure, the increase of compressive strength of concrete of (0.5 and 0.75%) PO samples in comparison with plain concrete. It seems that, we can find the reason of increase in compressive strength, particularly in relation to the 0.75% PO sample compared with control sample, in higher density of mix design and concrete components adhesion. It seems that adding Polyolefin fibers to concrete has led to better location of concrete aggregates and ingredients, and a compact structure has been created against compressive loads[7]while the compressive strength at 1% PO began to decrease due to density reduction .Figure (6) shows the compressive strength variable percentage of MgO powder and 0.75% Vf of PO fibers concrete samples tested at ages 28 day, where the highest compressive strength of the mixture which addition 1 % of MgO powder with 0.75% PO fiber where the percentage increases at 28 day compared to the reference mixture. The reason for this increase may be due to the adding 1% high fineness of MgO which leads to interaction in the early ages in addition to treatment with autoclave that will accelerate the chemical interaction of MgO powder which gives the result of the interaction larger than the space that was occupied before the interaction which leads to reduce pores and cracks capillary. From Figure, it can be seen also that there is a reduction in compressive strength when adding 5% MgO powder with 0.75%PO fiber compared to the reference mixture. The reason may be due to the interaction of a large proportion of MgO powder and that the reaction products occupy space greater than the void volume located inside the concrete structure which leading to cracked the structural concrete construction and thus reduce the compressive strength[9].
Figure (5) Compressive strength of concrete polyolefin fibers.

Figure (6) Compressive strength of concrete (C+0.75PO) Versace magnesia powder.

5.3 Flexural strength
Flexural strength of samples aged 28 days was tested for three samples per design and the average results are presented in figure (6) and (7). As can be seen in Figure (6) increasing the fiber content, the flexural strength of concrete examples has been increased. The figure show the flexural strength of (0.5 and 0.75) % V_f of polyolefin fiber increase compared with reference sample. Because by using Polyolefin fiber because the fiber bridging that prevent crack propagation. The 1% fibers ample having better performance than reference sample. Figure (7) show that highest value of flexural strength at 1% MgO powder concrete mixture and 0.75% polyolefin fibers compared to other mixtures. The reason for that is of expansion product that fill the voids and present spaces between the concrete component. While at increase the dosage of MgO powder the flexural strength decrease due to excessive expansion that cause micro crack when concrete subjected to tension.
6. Conclusions

In this study, the polyolefin fiber volume fraction (0.5, 0.75 and 1%) and the amount of added MgO powder (1, 3 and 5%) were varied for concrete mixes. Based on the experimental results, the following conclusions can be drawn:

1. The optimum density was obtained with (1%MgO–cement ratio +0.75 vol. % Polyolefin fiber).
2. The compressive strength could be slightly improved with the addition of polyolefin fiber, the optimal fiber content tend to be 1 vol. % and the increase ratio depends on the content of polyolefin fiber.
3. With the addition of 1 % MgO-cement ratio polyolefin fiber reinforced composite, the compressive strength showed a certain extent increase, beside the flexural strength enhanced, The optimal MgO - cement ratio tend to be 5%. 4. By increasing the MgO content to the fiber reinforced concrete the compressive and flexural strength tend to decrease.
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