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Evaluation of the compressive strength and permeability of graphene oxide-reinforced concrete by using the results of the cylindrical chamber method

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ABSTRACT: Water permeability in cement materials is influenced by internal factors, including the type of porous network of cement materials, and external factors, including applied pressure. In this study, the effect of graphene oxide on the compressive strength and anisotropy of the concrete samples and also the effect of applying hydrostatic pressure on the permeability of concrete reinforced with graphene oxide (GO) have been investigated. One of the important reasons for not using graphene in cement composites is its hydrophobicity, which causes the inappropriate distribution of graphene in the structure. The hydrophobic properties of graphene can be converted into hydrophilic properties through the process of chemical functionalization or physical coating. The results of the compressive strength of concrete indicate that the use of these particles in the concrete mixture can increase the compressive strength and reduce the anisotropy in the strength compared to the control sample. This issue can be considered due to the random orientation of graphene oxide sheets in the volume of concrete. The results also show that the addition of a small amount of graphene oxide can reduce the permeability of concrete. In fact, by adding these nanoparticles, it is possible to improve the characteristics of water transfer in concrete and subsequently the durability of it.

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1- Introduction

In the design of concrete structures, in addition to strength, durability should also be considered by designers. In other words, a concrete structure must be able to serve under environmental conditions. Permeability can be considered one of the most important parameters in controlling the strength and durability of concrete [1, 2].

Along with the advancement of nanotechnology, nanofibers with extraordinary performance, such as carbon nanotubes and graphene oxide nanoparticles (GO) have been produced, which can improve the performance of cement-based materials.

Since the durability of concrete structures depends significantly on their permeability and due to the lack of studies in this field on concrete reinforced with graphene oxide, in this research the effect of graphene oxide on the permeability of concrete is investigated. The working process is that the samples of concrete with different percentages of graphene oxide are subjected to permeability tests under different hydrostatic pressures. Permeability tests have been performed using a "cylindrical chamber" device [3]. The advantages of this device can be mentioned as the low cost of testing, high accuracy and the possibility of testing on site. Also, in order to investigate the compressive strength of concrete reinforced with graphene oxide as well as the anisotropy, the compressive strength test was carried out in two directions of concrete casting and perpendicular to it.

2- Methodology

2- 1- Water penetration test

Type II Portland cement (455 kg/m^3), gravel (900 kg/m^3) and sand (1100 kg/m^3) were used in the mix design. The water to cement ratio is considered 0.5 for all samples and GO values vary from (0-0.2)% by weight of cement (bwoc). In this study, in order to better disperse GO in water, the ultrasonic bath technique as well as superplasticizers (SP); based on modified polycarboxylate; were used [4]. SP was added to the mix at the rate of 0.5% bwoc. Concrete penetration tests have been performed using a "cylindrical chamber" device, which is a new method for measuring permeability [4].

2- 2- Compressive strength test

The compressive strength of each concrete sample was determined based on the ASTM standard [5]. Samples are placed centrally on the main plate and under the jack of the machine. The load is applied to the sample gradually by the jack. The maximum load is recorded and the stress-strain curve can be calculated by the device.

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Table 1. Compressive strength test results.

Mix No.	f_c 28 days (Mpa)	Increase in 28-days strength (%)	f_c 90 days (Mpa)	Increase in 90-days strength (%)
C0	32	-	36	-
CGO-0.03	35.1	9.7	45.72	27
CGO-0.05	35.9	12.2	51.2	42.2
CGO-0.1	40.2	25.6	54	50
CGO-0.2	38.9	21.6	52.8	46.6

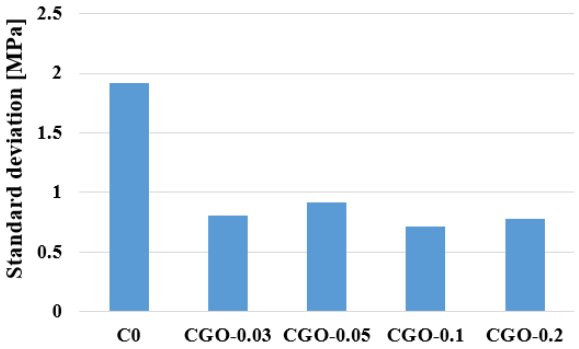

Fig. 1. Standard deviation of compressive strength results.

3- Results and Discussion

3- 1- Penetration results

In order to investigate the effect of graphene oxide nanoparticles on the permeability of concrete, a permeability test was performed on concrete samples. Based on the obtained results, adding small amounts of graphene oxide can lead to a decrease in the volume of water penetration in concrete compared to control samples. This reduction can be due to the improvement of the hydration process.

3- 2- Compressive strength results

To evaluate the effect of graphene oxide nanoparticles on anisotropy in the compressive strength, the samples were subjected to the compressive strength test in two directions of concrete casting and perpendicular to it. Since the compressive strength of cement composites depends on the age of the samples, in other words, on their degree of hydration, the compressive strength test was performed on the samples at the age of 28 and 90 days. The results of the compressive strength test in the direction of concreting are summarized in Table 1. The results indicate a significant increase in compressive strength in samples reinforced with graphene oxide sheets compared to the control sample. According to the test results, adding graphene oxide to concrete increases the compressive strength by 25% in the 28-day samples compared to the control samples. The results of the 90-day compressive strength of the samples also indicate an increase in the compressive strength by 50% compared to the control samples. As can be seen from the results, the increase in the compressive strength of the samples containing graphene oxide at the age of 90 days is more than at the age of 28 days. The increase in compressive strength can be attributed to the effect of graphene oxide in improving the cement hydration process, which leads to the formation of concrete with a denser structure and smaller holes in the concrete, as well as the bridging property of these nanoparticles due to its high contact surface and strong covalent bonds on the contact surface of hardened paste and graphene oxide sheets [6]. By further examining the results, it can be seen that in the concrete sample with 0.2% graphene oxide, the compressive strength has decreased by about 3-4% compared to the sample containing 0.1%. Considering the low percentages of graphene oxide consumed and the desired flow of the samples, the decrease in strength can be due to the deformation of the crystals resulting from the cement hydration process with a change in the amount of graphene oxide in the hardened cement paste [7]. In fact, Shenghua et al.'s studies on SEM photographs taken from cement composites with different percentages of graphene oxide show that the amount of use of these nanoparticles is effective in the form of crystals formed on a micro-scale. So that with the change in the amount of graphene oxide and the subsequent change in the shape of the crystals, the resistances change [7].

4- Conclusion

The results are as follows:

The results of the compressive strength test in two directions of concrete pouring and the direction perpendicular to it showed that the addition of graphene oxide reduces the anisotropy in the strength. Because the maximum standard deviation of strength for concrete reinforced with graphene oxide is less than that of control concrete. The small effect on the strength anisotropy in the reinforced samples can be attributed to the random orientation of the graphene oxide sheets in the volume of concrete.

The results of the compressive strength test of concrete samples at the age of 28 and 90 days showed an increase of 25% and 50%, respectively, in the concrete sample reinforced with 0.1% in comparison with control samples. Improving

the structure at the nano level and delaying the formation of microcracks during loading in the samples reinforced by these nanoparticles, as well as the bridging property of graphene oxide due to its high contact surface and strong covalent bonds at the contact surface of the hard paste, can be the reasons for increasing the compressive strength of concrete.

With an increase in the amount of graphene oxide, the total volume of permeated water decreases under constant hydrostatic pressure.

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