Effect of Graphene Oxide on Mechanical Properties of Recycled Mortar

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Abstract. The use of recycled aggregate as replacement of natural aggregate has increased in recent years in order to reduce the high consumption of natural resources in construction industry. This paper presents an experimental investigation on the effect of graphene oxide (GO) on the mechanical properties of recycled mortar. It is showed that the recycled mortar with GO has a better mechanical properties than the recycled mortar without GO. Microstructural analysis of the recycled mortar with GO showed to have much denser and better crystallization of hydration product.

1. Introduction

The rapid economic growth in China has encouraged a number of construction activities. Construction and demolition (C&D) wastes produced during new construction, renovation, and demolition of buildings and structures have become a serious problem in many countries [1]. Numerous studies have investigated the effects and impacts of C&D wastes on the environment, economy, and society [2]. In many countries a large amount of the recycled aggregate are derived from this waste. Owing to the increasing cost of landfill, the scarcity of natural resources coupled with the greater demand for aggregates in construction, the use of recycled aggregate to partially or totally replace the natural aggregate has, therefore, become a common practice.

A number of publications on the use of recycled fine aggregate in mortar or concrete concluded that strength and durability decreased [3, 4]. Moreover, the porosity of mortar containing recycled fine aggregate is normally larger than that of the mortar made with natural sand [4, 5]. This is attributed to the large surface area and poor surface quality of the recycled fine aggregate, which creates a weak interface transition zone (ITZ) and thus decreases bonding between the matrix and the fine aggregate [6, 7].

Based on the abovementioned studies, most research on recycled aggregate has focused on the mechanical properties, durability and damping capability of recycled mortar or recycled concrete. There are very few studies on the mechanical properties of recycled mortar with GO. As important performance indicators of materials, mechanical properties are critical to the structural dynamic response, materials damage. Currently, most of the techniques aim to increase the mechanical properties of structures by decreasing the recycled aggregate. Therefore, the attempt of this paper is to
investigate the effect of GO on the properties of recycled mortar, including workability, flexural and compressive strengths.

2. Materials and experimental procedure

2.1. Cement and chemical admixture

| Ingredient | CaO | SiO₂ | Al₃O₃ | Fe₂O₃ | MgO | SO₃ | K₂O | Na₂O | LOI |
|------------|-----|------|-------|-------|-----|-----|-----|------|-----|
| Content (mass %) | 64.42 | 20.52 | 5.62 | 3.78 | 2.11 | 2.10 | 0.28 | 0.20 | 0.87 |

Ordinary Portland Cement (OPC) type 42.5R was used as the binder material, conforming to the requirements of Chinese Standard GB175-2007 [8]. The chemical compositions and physical properties of the cement used are shown in Table 1.

Mixing water was normal tap water, conforming to Chinese Standard JGJ63-2006 [9]. In order to ensure the uniform dispersion of GO, this study uses the polycarboxylate-based superplasticizer type of Sika TMS-YJ-1, confirming to the requirements of JG/T223-2007 [10].

2.2. Recycled sand

The recycled sand used in the experimental study reported here was obtained from a recycling plant, where mixed demolition wastes were processed by mechanical crushing, sieving and sorting operations. The recycled fine aggregate used is conformed to the requirements specified in GB/T25176-2010 [11], with fineness modulus at 2.39, 1.2% mud, and 0.8% clay lump. The other properties and grain-size distribution of the recycled sand are shown in Table 2.

| Sieve opening | Recycled sand |
|---------------|---------------|
| 9.5 mm        | 100           |
| 4.75 mm       | 100           |
| 2.36 mm       | 90            |
| 1.18 mm       | 60            |
| 600 µm        | 25            |
| 300 µm        | 15            |
| 150 µm        | 5             |
| Dry specific density (kg/m³) | 1930 |
| Packing density (kg/m³)       | 1250 |
| Surface dry specific density (kg/m³) | 2150 |

2.3. Preparation of GO

The GO (3g/L) was prepared by dispersing the graphite oxide powder into the mixture of water and polycarboxylate ether (PCE) superplasticizer (PCE/GO ratio of 1.3) with the help of ultrasonication. As mentioned earlier, if GO is to be fully utilized in materials, it must undergo proper dispersion. Based on previous investigations, the ultrasonication conditions were thus used as follows: the amplitude was set 20%, power 600W, frequency 20Hz and time 2 hours, titanium alloy probe width 20mm.
2.4. Mixtures proportioning and preparation

| Sample | Recycled sand (g) | Cement (g) | Water (g) | GO (g) | GO/Cement |
|--------|-------------------|------------|-----------|--------|-----------|
| R0     | 1350              | 450        | 300       | 0.00   | 0.00%     |
| R1     | 1350              | 450        | 300       | 0.225  | 0.05%     |
| R2     | 1350              | 450        | 300       | 0.45   | 0.10%     |
| R3     | 1350              | 450        | 300       | 0.90   | 0.20%     |

The focus of this work is not on the development of recycled mortar mixture, but on the use of advanced techniques to examine the effect of GO on the dynamical mechanical properties of recycled mortar. The mix proportions of various recycled mortar are given in Table 3. The aqueous GO suspensions were made with the mixing water and the GO substances. Based on previous investigations and the high water absorption rate of recycled sand, the water/cement ratio (w/c) was selected as 0.66 to ensure the adequate workability of recycled mortar. Based on the work [12] the amounts of GO to be used in the recycled mortar are 0.00%, 0.05%, 0.10% and 0.20% by mass of cement respectively.

2.5. Test methods

The effect of GO on the workability of cement paste and recycled mortar were evaluated by a mini-slump test. After preparation of cement paste and recycled mortar, the fresh mixture was poured into a mini-cone (top inside diameter: 36 mm, bottom inside diameter: 60 mm, height: 60 mm) for the fluidity evaluation. The testing method was tested according to the requirements of GB/T2419-2005 [13].

To examine the influence of GO added on the mechanical properties of recycled mortar, both the compression test and three-point bending test were conducted. The size of specimens used for the flexural strength tests was 40*40*160 mm and that used for the compressive strength test was 40*40*40 mm. These specimens were tested at 14 days and 28 days. The internal morphology of the recycled mortar was assessed by ESEM at 7 days. Moreover, the fracture surface morphology after the 28-day was assessed by environmental scanning electron microscopy (ESEM, type Quanta 200 FEG).

3. Results and discussions

3.1. Fluidity of recycled mortar

Immediately after mixing, the fresh mixture was measured by slump tests to determine the workability of the cement paste and the recycled mortar samples (R0, R1, R2, R3). The results are shown in Fig.6 for mortar; both of them are with GO contents of 0.05 wt%, 0.10 wt%, and 0.20 wt%, respectively. Fig. 1 shows similar results for the recycled mortar, in which its workability decreased by 7.5%, 14.4%, and 18.8% when it was with GO contents of 0.05%, 0.10%, and 0.20%, respectively.
3.2. Mechanical properties

The results of flexural strength tests of recycled mortar with different GO contents at different ages are shown in Fig. 2 (a). The flexural strength of the recycled mortar without GO was found to be 5.0 and 6.3 MPa at 14 days and 28 days, respectively, which are in agreement with the values reported in literature [14]. The flexural strength of the recycled mortar with GO was found greater than that of the recycled mortar without GO. The maximum increment was found to be about 22.0% and 41.3% when the recycled mortar contains 0.2% GO at 14 days and 28 days, respectively.

The compressive strengths of samples with different amounts of GO at 14 and 28 days were plotted in Fig. 2 (b). It is seen that the compressive strength of the mortar increased with the increase of GO added in the mortar. Also, it is shown that, the longer the cured age, the higher the compressive strength. The maximum increment of the compressive strength was found to be about 16.4% and 16.2% for the recycled mortar containing 0.2% GO at 14, and 28 days, respectively.

The results indicate that, under static conditions, both the flexural and compressive strengths increased with the addition of GO in the recycled mortar. As a consequence, the increase in flexural and compressive strengths suggests that the bond developed between GO and mortar is effective under static conditions and thus the addition of GO has a positive impact on the process of hydration, which could directly transform into mechanical properties. In addition, GO, as a nano-scale material, can easily fill the pores of the cement matrix, and make the material more solid or denser. Note that, if the matrix is denser in a cementitious material, the mechanical properties of the material would generally be better, as is demonstrated in literature [15].
3.3. Microstructure characterization
High resolution SEM images were obtained for the recycled mortar with the different amounts of GO to examine the morphological changes at high magnification. Fig. 3 A shows the crystal morphology of recycled mortar without GO cured for 7-day. It can be seen that many pores and cracks exist in CSH and there are many lower CSH density areas. In addition, it can also be found that cracks usually pass through dense hydration products in a straight-through manner. Fig. 3 B shows the crystal morphology of the recycled mortar with GO cured for 7-day. It was found that the production of thin non-uniform platelets and entangled network of rod like crystals were observed at various locations in the GO sample after 7 days. The high density CSH can be seen with the addition of GO. Besides, the area of high density increased with the increase of added GO. In particular, as compared with other fillers, GO exhibits unique two-dimensional structure which can effectively deflect, or force cracks to tilt and twist around GO. The process may help to impede fine cracks.

![Figure 3 SEM images in mortar sample (A) and in GO-recycled mortar (B) after 7 days curing.](image)

4. Conclusion
In this study, the workability, mechanical properties, and microstructure of the recycled mortar incorporating GO at different amounts of 0.05%, 0.1%, 0.2% by mass have been investigated. Based on the presented experimental results, the following conclusions can be drawn.

1. The addition of GO decreases the workability of cement paste and recycled mortar at different amounts of 0.05%, 0.1%, 0.2% by mass of cement, respectively.

2. The use of GO increases the flexural and compressive strengths of recycled mortar at 14, 28 days. The reinforcing mechanisms can be attributed to the accelerated degree of cement hydration, better load-transfer efficiency, compact microstructure and refined cracks.

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