Effect of Graphene Oxide on the Damping Capability of Recycled Mortar

Jing-Jie Wei¹, Wu-Jian Long¹*, Chang-Le Fang¹, Hao-Dao Li¹, Yue-Gui Guo¹

¹ Guangdong Provincial Key Laboratory of Durability for Marine Civil Engineering, Shenzhen Durability Center for Civil Engineering, College of Civil Engineering, Shenzhen University, Shenzhen 518060, Guangdong, P.R. China

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 damping capability of recycled mortar. The effect of GO on damping capability was examined by using dynamic mechanical analyzer (DMA), It is showed that the recycled mortar with GO has a better damping capability than the recycled mortar without GO. Microstructural analysis of the recycled mortar with GO showed to have much denser and better crystallization of hydration products.

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]. 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 [2, 3]. Moreover, the porosity of mortar containing recycled fine aggregate is normally larger than 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].

Based on the abovementioned studies, there are not only very few studies on the properties of recycled mortar with GO, but also on the variation of the dynamic mechanical properties of recycled mortar with GO at different temperatures. As important performance indicators of materials, dynamic mechanical properties are critical to the structural dynamic response, materials damage and damping energy consumption. Currently, most of the techniques aim to increase the damping properties of structures by installing with various damping devices such as machines or hydraulic pressure systems in order to reduce the vibration of structures. Therefore, the attempt of this paper is to investigate the effect of GO on the properties of recycled mortar, including damping capability and microstructure.
2. Materials and experimental procedure

2.1. Cement and chemical admixture

Ordinary Portland Cement (OPC) type 42.5R was used as the binder material, conforming to the requirements of Chinese Standard GB175-2007 [7]. The chemical compositions and physical properties of the cement used are shown in Table 1. 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[8].

Table 1. Chemical compositions and physical properties of cement.

| Ingredient | CaO | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | MgO | SO$_3$ | K$_2$O | Na$_2$O | LOI |
|------------|-----|---------|-------------|-------------|-----|--------|--------|--------|-----|
| Content (mass %) | 64.42 | 20.52 | 5.62 | 3.78 | 2.11 | 2.10 | 0.28 | 0.20 | 0.87 |

2.2. Recycled fine aggregate

The recycled fine aggregate 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. All of the recycled fine aggregate was sieved first to obtain various grading sizes and the different fractions were kept in sealed containers to prevent humidity exchange with the surrounding environment. The recycled fine aggregate used is conformed to the requirements specified in GB/T25176-2010[9], with fineness modulus at 2.39, 1.2% mud, and 0.8% clay lump. The grading curve of the recycled fine aggregate is shown in Figure 1.

![Figure 1. Particle-size distribution of recycled fine aggregate.](image)

2.3. Mixtures proportioning and preparation

The focus of this work is not on the development of recycled mortar, but on the use of advanced techniques to examine the effect of GO on the damping capability of recycled mortar. The mix proportions of various recycled mortar are given in Table 2. 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 [10] 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, while the PCE/GO ratio used was 1.3. The mixture was poured into the customized molds of 30*30*30 mm for the DMA test.

Table 2. Mix proportions of recycled Mortar

| Sample | Recycled sand (g) | Cement (g) | Water (g) | W/C | GO (g) | GO/Cement | PCE/GO |
|--------|------------------|------------|-----------|-----|--------|-----------|--------|
| R$_0$  | 1350             | 450        | 300       | 0.66| 0.00   | 0.00%     | 1.3    |
| R$_1$  | 1350             | 450        | 300       | 0.66| 0.225  | 0.05%     | 1.3    |
| R$_2$  | 1350             | 450        | 300       | 0.66| 0.45   | 0.10%     | 1.3    |
| R$_3$  | 1350             | 450        | 300       | 0.66| 0.90   | 0.20%     | 1.3    |

Note: R is the recycled mortar, P is the cement paste.
2.4. Test methods
The dynamic mechanical properties of materials are often measured by using the dynamic mechanical analyzer. The loss factor can be obtained from DMA testing. In this study, the dynamic mechanical property test was carried out by using a dynamic mechanical analyzer at a frequency of 1Hz, a heating rate of 5°C/min, temperature ranging from −50 to 60°C, a maximum dynamic force of 80 N, and a static force of -100 N. The tests were carried out on the specimens at the age of 14 days and 28 days. Based on the repeatability of DMA tests proved by Yuan et al. [11], DMA tests were carried out on the same sample.

The element analysis of cement paste samples was carried out using X-ray diffraction (XRD). The XRD analysis was performed by using X-ray diffractometer (XRD, type PANalytical) equipped with monochromatic Cu-Kα radiation at 40 kV and 40 mA. The internal morphology of the recycled mortar was assessed by ESEM at 7 days. Moreover, the fracture surface morphology after the 28-day DMA test was assessed by environmental scanning electron microscopy (ESEM, type Quanta 200 FEG).

3. Results and discussions

3.1. Damping capability
The results of the tan δ analysis for the R₀, R₁, R₂ and R₃ recycled mortar specimens are shown in figures 2(a) and (b). It can be observed that the damping capability properties of R₀ are different from those of other specimens because of the different GO/Cement ratios. When the w/c and sand-cement ratio (s/c) were the same, the loss factor of GO recycled mortar (R₁, R₂ or R₃) was higher than that of recycled mortar without GO (R₀) at the temperature between -50 °C and 60 °C; the loss factor of recycled mortar increased with the amount of added GO. Thus, GO addition has a positive effect on the loss factor of recycled mortar. The ability of GO to enhance the damping capability is due to its nano-material nature, which improves the interface between individual components in the mixture, and non-uniform stress distribution under external force [12].

3.2. Microstructure characterization

3.2.1. X-ray diffraction analysis. Figure 3 shows the XRD patterns of the cement composites in the recycled mortar with different GO additions after 28-day of curing. The phases detected are the usual...
cement hydrates as CSH, CH and Calcium carbonate, Calcium carboaluminate hydrate [15]. Based on XRD analysis, phases of CH, CSH+CC and CCA+CH have the highest characteristic peaks, which are located around 18, 29 and 48, respectively.

Since the weight fractions of GO used in the recycled mortar were all rather small, there are no peaks corresponding to GO in the XRD patterns of GO-recycled mortar samples. Therefore, no major difference could be observed in the diffraction patterns of the different samples, indicating they all have similar mineralogical compositions. However, the increase of peaks was seen in the by-product of the cement hydration created through the reaction of the –COOH functional groups with C$_2$S, C$_3$S phase. The quantity of CH at early ages can be evaluated as the degree of hydration and the amount of C-S-H generation; while the amorphous phase can be considered as the contributor to strength [16]. These mineralogical results indicate that GO can promote hydration reactions. As a result, the increase of calcium carboaluminate hydrated phase may contribute to enhanced energy absorption and storage modulus of the recycled mortar, which is in good correlation with the results of damping capability analysis.

![Figure 3. XRD results at 28 days.](image)

### 3.2.2. SEM analysis

Figure 4 A-B 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. Figure 4 C-D 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. The results of the microanalysis agree well with those examined in dynamical mechanical analysis tests. Because capillary pores, CSH density, cement hydrates, sand are the main factors affecting loss factor of recycled mortar [17].

![Figure 4. SEM images in recycled mortar (A, B) and in GO-recycled mortar (C,D) after 7days curing.](image)

### 4. Conclusion

In this study, the workability, dynamical 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 loss factor (damping capability) of the GO-recycled mortar (R₁, R₂ and R₃) was higher than that of the recycled mortar without GO (R₀) at the temperature between -50 °C and 60 °C. The loss factor of the GO-recycled mortar increased with the increased of GO addition. The ability of GO to enhance the damping capability is due to its nano-material nature which improves the interface in the mixture, and the non-uniform stress distribution under external force.

2. The addition of GO in cementitious materials can promote the hydration of cement.

References
[1] Nagapan S, Rahman I A, Asmi A. 2012 Int. J. Adv. Appl. Sci. 1(1) 2252-8814.
[2] Dhir R K, Limbachiya M C, Leelawat T, et al. 1999 Proc. Inst. Civil Eng. Struct. Build. 134(3) 257-74.
[3] Ryu J S 2002 Mag. Concr. Res. 54(1) 7-12.
[4] Le T, Saout G L, Garcia-Diaz E, et al. 2017 Constr. Build. Mater. 141 479-90.
[5] Kou S C, Poon C S, Etxeberria M 2011 Cem. Conc. Comp. 33(2) 286-91.
[6] Bosque I F S D, Zhu W, Howind T, et al. 2017 Cem. Conc. Comp. 81 25-34.
[7] GB/T 175-2007, Common Portland cement. Chinese national standard; 2007.
[8] GB/T 25176-2010, 2010 Recycled fine aggregate for concrete and mortar, Chinese national standard.
[9] GB/T 25176-2010, 2010 Recycled fine aggregate for concrete and mortar, Chinese national standard.
[10] Lei B, Wang X, Rao C, et al. 2015 Recycled masonry mortar used for civil engineering applications, comprises recycled aggregate, cement, fly ash, aluminum slag, graphene oxide, composite additive and water, in preset weight ratio, China, CN104402351-A; 2015.
[11] Yuan Q, Liu W, Pan Y R, et al. 2015 J. Mater. Civ. Eng. 28(3) 04015154.
[12] Zhang H, Zhao Y, Meng T, et al. 2015 Constr. Build. Mater. 95 721-35.
[13] Shang Y, Zhang D, Yang C, et al. 2015 Constr. Build. Mater. 96 20-8.
[14] Ping S 2016 Poly. Comp. 8(5) 308-13.
[15] Fang L, Yuan Q, Deng D, et al. 2107 J. Mater. Civ. Eng. 29(8) 04017080.
[16] Yang C, Huang R 1996 Cem. Conc. Res. 26(1) 83–91.
[17] Fenu L, Forni D, Cadoni E 2016 Comp. Part B Eng. 92(8) 142-50.

Acknowledgement
The authors gratefully acknowledge the financial support provided by the National Natural Science Foundation of China (No.51578341, No. 51278306).