Supplement

Influence of Polycarboxylate Ether Type and Dosage on Electrokinetic and Hydrodynamic Descriptors of Graphene Oxide Suspensions in an Alkaline Model Medium

Zaid Khaiqani[1*], Katalin Kopecskó[2]

[1] Department of Construction Materials and Technologies, Faculty of Civil Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary
[2] Department of Engineering Geology and Geotechnics, Faculty of Civil Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary
* Corresponding author, e-mail: zaid.abdulhussein695@edu.bme.hu

1 The characterization of graphene oxide (GO)

The as-received graphene oxide (GO) was described using supplier-provided public characterization data [1]. These data document the morphology, approximate sheet height, structural disorder, surface chemistry, and elemental composition of the supplied GO stock dispersion before its use in preparing the GO:PCE suspensions. They are used here as material documentation for the present study and were not generated by the authors. The characterization includes atomic force microscopy (AFM), Raman spectroscopy, scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and Fourier-transform infrared spectroscopy with attenuated total reflectance (FTIR-ATR).

1.1 Atomic force microscopy (AFM)

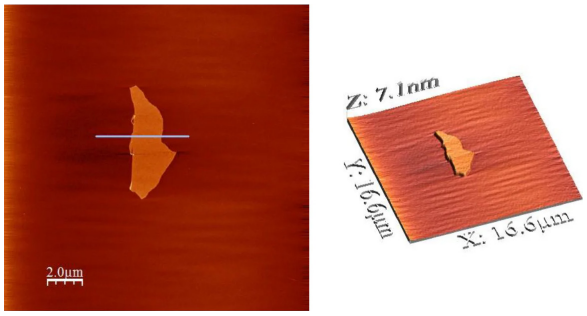
The supplier used AFM to estimate the lateral dimensions and apparent sheet height of the graphene oxide. The 10 mg/mL GO stock dispersion was diluted to 1 ppm before AFM analysis. The AFM images show thin, sheet-like GO flakes with lateral dimensions in the micrometer range. The supplier-reported lateral dimensions were variable, with most sheets showing at least one lateral dimension greater than 5 µm. The height profile indicated an apparent sheet height below approximately 2 nm. This is consistent with predominantly single-layer to few-layer graphene oxide, although AFM height should not be interpreted as an exact layer count, as adsorbed water, oxygen-containing groups, and substrate effects can influence the measured height. The AFM characterization is shown in Fig. S1.

1.2 Raman spectroscopy

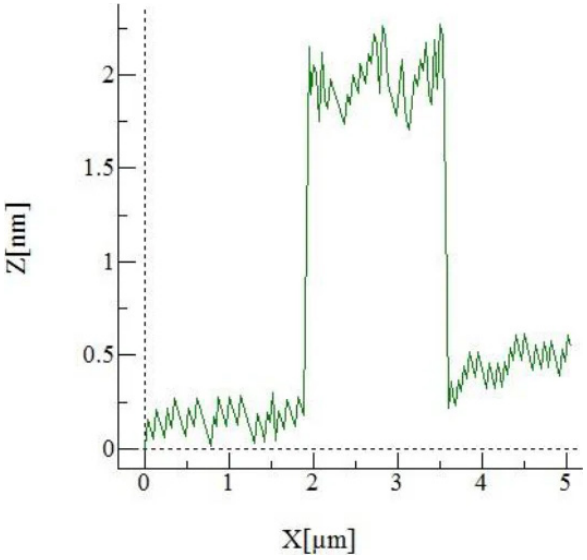
The supplier used Raman spectroscopy to evaluate structural disorder in the graphene oxide. The spectrum shows the characteristic D and G bands of oxidized graphitic materials, with an ID/IG ratio of approximately 1. This indicates a defective, oxidized carbon framework typical of graphene oxide. It should not be interpreted alone as quantitative proof of the degree of oxidation or layer number. The Raman data, together with the supplier's SEM-based false-color layer interpretation, are consistent with the presence of many single-layer GO regions, as shown in Fig. S2. Some apparent two-layer and thicker regions were also observed; however, these may partly result from sheet overlap during sample preparation.

1.3 Scanning electron microscopy (SEM)

The supplier used SEM to examine the lateral dimensions of the GO sheets and to detect visible impurities. The GO stock dispersion was diluted to 0.00025% and dried on a silicon wafer before imaging. The SEM image in Fig. S3 shows thin, overlapping GO sheets with lateral dimensions exceeding 5 µm, in agreement with the AFM observations. Small bright spots were observed in the SEM image



(a)



(b)

Fig. S1 Supplier-provided AFM characterization of graphene oxide [1]: (a) AFM height image with the corresponding three-dimensional view of a diluted GO sheet; (b) height profile measured along the line marked in Fig. S1 (a)

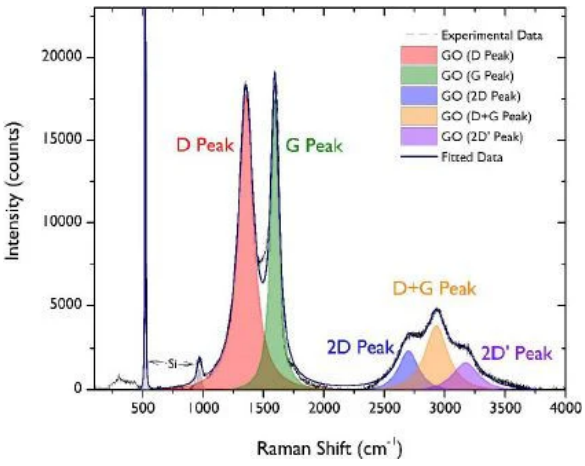
and were attributed by the supplier to minor metallic impurities. The supplier-reported trace-metal content of the 1 wt.% aqueous GO dispersion is below 0.1%.

1.4 X-ray photoelectron spectroscopy

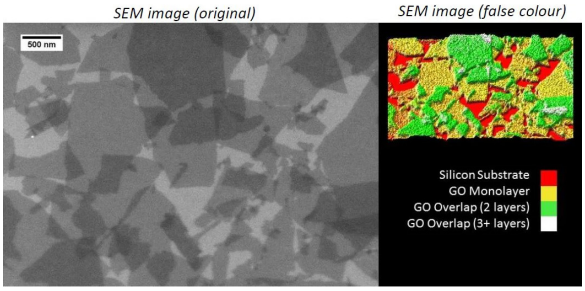
The supplier used XPS to assess the surface elemental composition of freeze-dried graphene oxide powder. The survey spectrum shows carbon and oxygen as the dominant elements, which is consistent with the supplier-reported composition range. The XPS data are used here only as supplier-provided material documentation. No peak deconvolution, detailed bonding analysis, or quantitative functional-group distribution is inferred from this spectrum in the present study. The XPS survey spectrum is shown in Fig. S4.

1.5 Fourier-transform infrared spectroscopy with attenuated total reflectance

The supplier used FTIR-ATR to identify functional groups present in the freeze-dried graphene oxide



(a)



(b)

Fig. S2 Supplier-provided Raman and SEM characterization of graphene oxide [1]: (a) Raman spectrum showing the D and G bands and supplier-provided fitted peak components; (b) original SEM image and supplier-provided false-color interpretation of apparent GO monolayer, overlapping two-layer, and overlapping multilayer regions

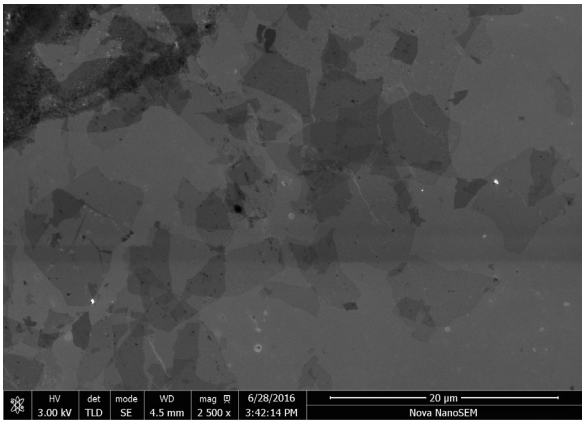


Fig. S3 Supplier-provided SEM image of dried graphene oxide sheets on a silicon wafer after dilution of the stock dispersion [1]

powder. The spectrum shows bands associated with hydroxyl, carbonyl/carboxyl, C=C, and C–O-related groups. These oxygen-containing groups are relevant because they can contribute to GO's hydrophilicity and electrokinetic behavior in alkaline suspension and may influence its interaction with PCE during GO:PCE suspension preparation. The FTIR-ATR data support only qualitative identification of functional

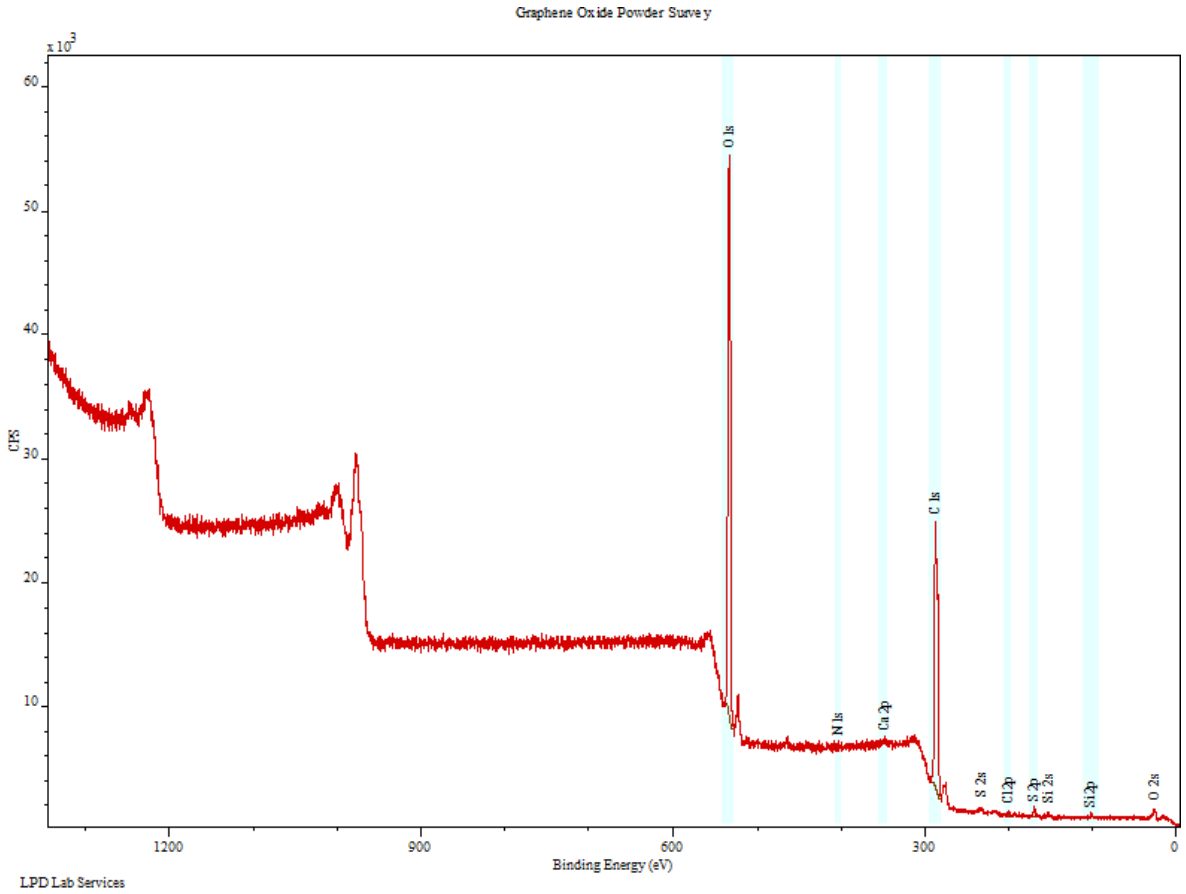


Fig. S4 Supplier-provided XPS survey spectrum of freeze-dried graphene oxide powder [1]

groups; quantitative functional-group fractions were not determined. The FTIR-ATR spectrum is shown in Fig. S5, and the supplier-reported peak assignments are summarized in Table S1.

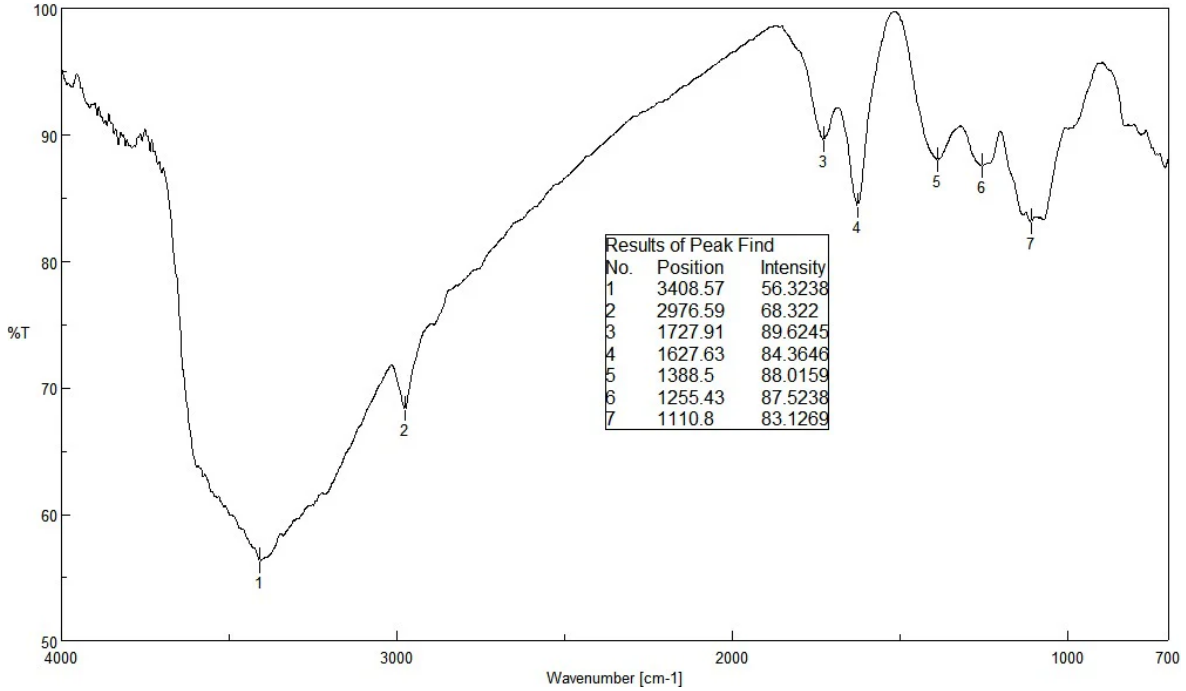


Fig. S5 Supplier-provided FTIR-ATR spectrum of freeze-dried graphene oxide powder [1]

Table S1 Supplier-reported FTIR-ATR peak assignments for graphene oxide [1]

Wave number (cm^{-1})	3408.57	2976.59	1727.91	1627.63	1388.5	1255.43	1110.8
Possible bond assignment	O–H	Aliphatic C–H	C=O carboxyl vibration	C=C	C–O	C–O	C–O

2 Representative DLS intensity-weighted hydrodynamic size distributions

Representative DLS intensity-weighted hydrodynamic size distributions are shown in Fig. S6.

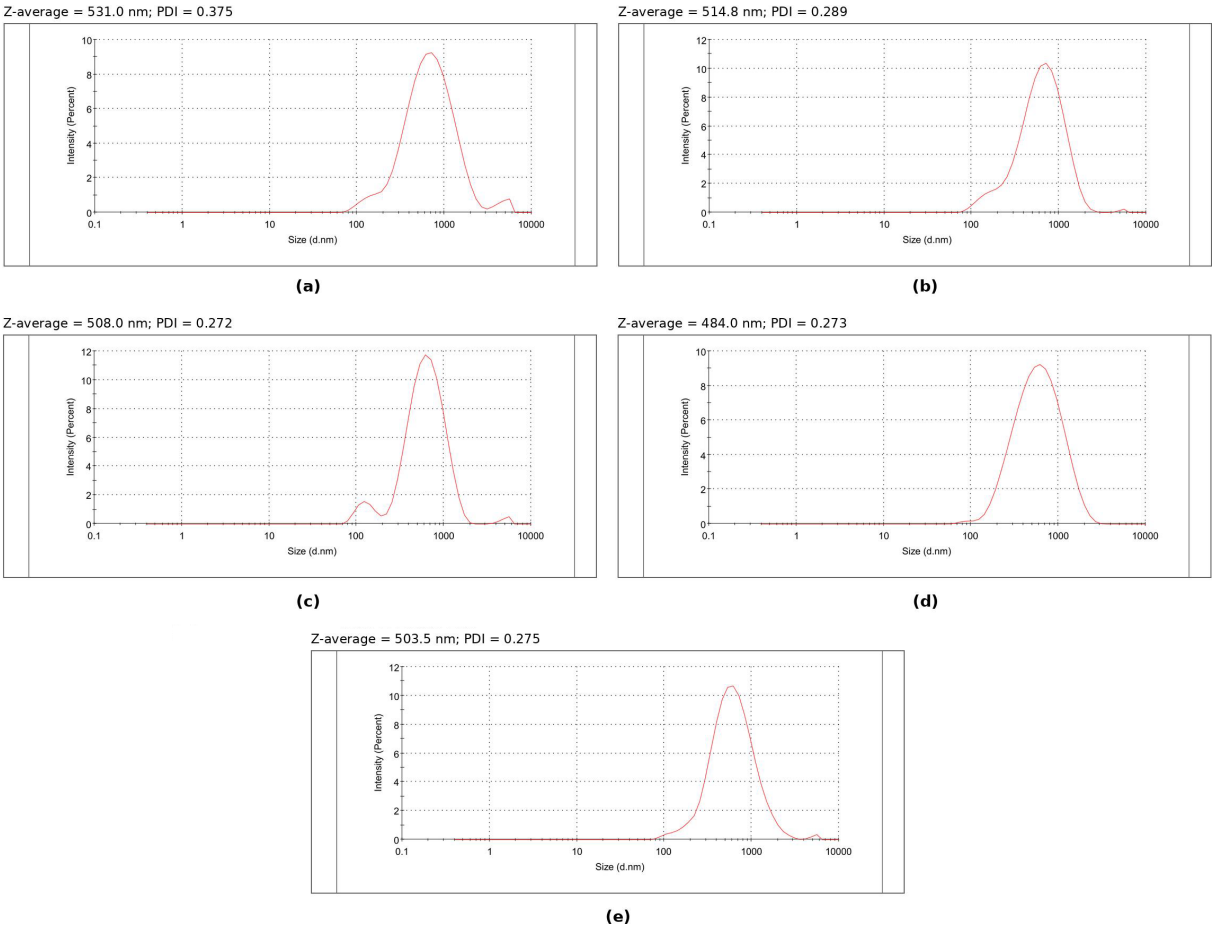


Fig. S6 Representative DLS intensity-weighted hydrodynamic size distributions of the control GO suspension and selected GO-PCE suspensions at a GO:PCE mass ratio of 1:5 in the NaOH-adjusted alkaline model medium: (a) GOC 1:0; (b) ACE 300 1:5; (c) VC-4269 1:5; (d) VC-6711 1:5; (e) MCPL-2695 1:5. The distributions support the interpretation of the Z-average hydrodynamic diameter and PDI values reported in the main text and should not be interpreted as direct lateral size distributions of GO sheets

References

[1] GOgraphene "Graphene Oxide Analysis", [online] Available at: https://www.go-graphene.com/pages/graphene-oxide-analysis [Accessed: 25 May 2026]