STUDY ON THE FABRICATION AND MECHANICAL CHARACTERIZATION OF GRAPHENE-EPOXY NANOCOMPOSITE MATERIAL

MD. NAZMUS SAKIB

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that, We have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

(Supervisor's Signature)

Full Name : TS. DR. NAFRIZUAN BIN MAT YAHYA

Position : SENIOR LECTURER

Date : 24/01/2022

DR. RADHIYAH BINTI ABD AZIZ
PENSYARAH KANAN
FAKULTI TEKNOLOGI KEJURUTERAAN
PEMBUATAN & MEKATRONIK ,
UNIVERSITI MALAYSIA PAHANG
Tel: 09-424 5800 Faks: 09-424 5888

(Co-supervisor's Signature)

Full Name : DR. RADHIYAH BINTI ABD AZIZ

Position : SENIOR LECTURER

Date : 24/01/2022

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institution.

(Student's Signature)

Full Name : MD. NAZMUS SAKIB

ID Number : MFA19006

Date : 24/01/2022

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ABSTRAK

Penggunaan kereta yang berlebihan menyebabkan isu alam sekitar dan pelepasan gas rumah hijau. Penyelidik dan pengeluar cuba mengatasi cabaran keselamatan alam sekitar dengan menghasilkan kereta yang jimat bahan api dan diminimumkan berat dengan bantuan bahan komposit polimer ringan dan bukannya bahan berat. Epoksi sebagai polimer termoset ditambah dengan bahan pengisi yang betul menghasilkan bahan nanokomposit, yang meningkatkan sifat mekanikal, kimia, elektrik dan haba, keserasian tinggi, kos rendah dan pengecutan memainkan peranan penting dalam hal ini. Antara bahan pengisi lain, Graphene, bahan atom dua dimensi paling nipis, telah direndam sebagai bahan revolusioner dan mencetuskan kesibukan penyelidikan dan inovasi, diutamakan kerana sifatnya yang cemerlang dan luas permukaan khusus yang tinggi. Nanokomposit epoksi terubah suai graphene nanofiller kini tertakluk kepada penyelidikan yang intensif kerana ringan dan berpotensi dalam pelbagai aplikasi struktur dan berfungsi. Prestasi keseluruhan komposit polimer sebahagian besarnya bergantung pada peratusan isipadu/berat bagi serakan homogen pengisi tetulang dan pertalian yang kuat antara pengisi dan matriks polimer. Nanokomposit Graphene-Epoxy dan Graphene-Epoxy-SDS telah dibuat dengan tiga kepekatan (0.3, 0.5, 1) Graphene Oxide (GO) berbeza dengan teknik campuran larutan. Sodium Dodecyl Sulphate (SDS) telah digunakan sebagai surfaktan untuk grafena penyebaran homogen dalam matriks epoksi untuk mengatasi daya van der Waals yang kuat dan grafena pengagregatan semula. Graphene Oxide (GO) dan SDS telah tersebar dalam aseton melalui sonication, dan resin epoksi telah ditambah. Selepas mengeluarkan aseton dan menambah pengeras, campuran itu dituangkan ke dalam acuan silikon, dan kemudian nanokomposit diawetkan semalaman dalam ketuhar vakum. Nanokomposit dan Serbuk GO yang disediakan telah dicirikan oleh Mikroskopi elektron Penghantaran (TEM), Mikroskop Elektron Pengimbasan (SEM), X-Ray Penyebaran Tenaga (EDX), Difraktometer sinar-X (XRD), dan Spektroskopi Inframerah Transformasi Fourier (FTIR). Untuk menyiasat kesan pembebanan pengisi ke atas kekerasan sifat mekanikal, ujian tegangan dan lentur telah dilakukan. Nanokomposit Graphene-Epoxy, 0.5 kepekatan beban pengisi GO menunjukkan (11%) kekerasan yang lebih tinggi, di mana 1 kepekatan pengisi GO mempamerkan 7.4% kekuatan tegangan dan 8.33% kekuatan lenturan lebih tinggi berbanding dengan epoksi tulen. Nanokomposit Graphene-Epoxy-SDS telah disintesis dengan pemuatan SDS berterusan dengan tiga kepekatan berbeza (0.3, 0.5, 1) GO. Ia meningkatkan bahawa 0.5 kepekatan nanokomposit GO-Epoxy-SDS telah mempamerkan sifat mekanikal tertinggi, iaitu 24.1% kekerasan, 40.74% tegangan dan 37.01% kenaikan kekuatan lentur daripada matriks epoksi. Jadi 0.5 kepekatan pemuatan graphene disyorkan sebagai pemuatan optimum dalam kajian matriks epoksi ini, dan surfaktan SDS menunjukkan sifat yang lebih tinggi. Kajian ini akan membantu untuk digunakan dalam aplikasi struktur ringan, terutamanya dalam bahagian kereta dan pesawat.

ABSTRACT

Excessive use of automobiles causes environmental issues and greenhouse gas emissions. Researchers and producers try to overcome the challenges of environmental safety by producing fuel-efficient, weight minimized automobiles with the help of lightweight polymer composite materials instead of heavy materials. Epoxy as a thermoset polymer added with proper filler material produces nanocomposite material, which increased mechanical, chemical, electrical, and thermal properties, high compatibility, low cost, and shrinkage played significant roles in this regard. Among other filler materials, Graphene, the thinnest two-dimensional atomic material, has immerged as a revolutionary material and sparked a flurry of research and innovation, is preferred due to its outstanding properties and high specific surface area. Graphene nanofiller modified epoxy nanocomposite is currently subject to intense research due to its lightweight and potential in a wide range of structural and functional applications. The polymer composite's overall performance largely depends on the volume/weight percentage of the reinforcement fillers' homogenous dispersion and a strong affinity between the filler and the polymer matrix. Graphene-Epoxy and Graphene-Epoxy-SDS nanocomposite have been made with three different wt.% (0.3, 0.5, 1) of Graphene Oxide (GO) by solution mixing technique. Sodium Dodecyl Sulphate (SDS) has been used as a surfactant for homogenous dispersing graphene in the epoxy matrix to overcome strong van der Waals force and re-aggregation graphene. Graphene Oxide (GO) and SDS were dispersed in acetone by sonication, and epoxy resin was added. After removing the acetone and adding a hardener, the mixture was poured into silicon molds, and then the nanocomposite was cured overnight in a vacuum oven. The prepared nanocomposites and GO Powder were characterized by Transmission electron microscopy (TEM), Scanning Electron Microscope (SEM), Energy Dispersive X-Ray (EDX), X-ray Diffractometer XRD), and Fourier-Transform Infrared Spectroscopy (FTIR). To investigate the effect of filler loading on mechanical properties hardness, tensile and flexure tests were done. Graphene-Epoxy nanocomposite, 0.5 wt.% of GO filler loading showed (11%) higher hardness, whereas 1wt.% of GO filler exhibited 7.4% higher tensile and 8.33% flexure strength compare to pure epoxy. Graphene-Epoxy-SDS nanocomposite was synthesized with constant SDS loading with three different wt% (0.3, 0.5, 1) of GO. It enhanced that 0.5wt.% GO-Epoxy-SDS nanocomposite have exhibited the highest mechanical properties, which are 24.1% hardness, 40.74% tensile, and 37.01% flexure strength increment than the epoxy matrix. So 0.5wt% of graphene loading is recommended as optimum loading in this study of the epoxy matrix, and SDS surfactant demonstrated higher properties. This study would be helpful to use in lightweight structural applications, especially in automobile and aircraft parts.

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REFERENCES

Abdou, M. I., Ayad, M. I., Diab, A. S. M., Hassan, I. A., & Fadl, A. M. (2017). Influence of surface modified ilmenite/melamine formaldehyde composite on the anti-corrosion and mechanical properties of conventional polyamine cured epoxy for internal coating of gas and oil transmission pipelines. *Progress in Organic Coatings*, *113*, 1–14. https://doi.org/10.1016/j.porgcoat.2017.08.003

Abdullah, S. I., & Ansari, M. N. M. (2015). Mechanical properties of graphene oxide (GO)/epoxy composites. *HBRC Journal*, *11*(2), 151–156. https://doi.org/10.1016/j.hbrcj.2014.06.001

Ahmed A. Moosa, Ahmad Ramazani S. A., Faris Abdul Karim Kubba, M. R. (2017). Synergetic Effects of Graphene and Nonfunctionalized Carbon Nanotubes Hybrid Reinforced Epoxy Matrix on Mechanical , Thermal and Wettability Properties of Nanocomposites. *American Journal of Materials Science*, *7*(1), 1–11. https://doi.org/10.5923/j.materials.20170701.01

Ambrosi, A., Chua, C. K., Bonanni, A., & Pumera, M. (2014). Electrochemistry of graphene and related materials. In *Chemical Reviews* (Vol. 114, Issue 14, pp. 7150–7188). Chem Rev. https://doi.org/10.1021/cr500023c

An, X., Simmons, T., Shah, R., Wolfe, C., Lewis, K. M., Washington, M., Nayak, S. K., Talapatra, S., & Kar, S. (2010). Stable aqueous dispersions of noncovalently functionalized graphene from graphite and their multifunctional high-performance applications. *Nano Letters*, *10*(11), 4295–4301. https://doi.org/10.1021/nl903557p

An, Y., He, X., Yang, W., & Ding, Y. (2011). Effect of surfactants on the dispersion of multi-walled carbon nanotubes in epoxy resin. *Advanced Materials Research*, *221*, 1–7. https://doi.org/10.4028/www.scientific.net/AMR.221.1

Ashcroft, W. R. (1993). Curing agents for epoxy resins. *Chemistry and Technology of Epoxy Resins*, 37–71. https://doi.org/10.1007/978-94-011-2932-9_2

ASTM D1763 - 00(2013) Standard Specification for Epoxy Resins. (n.d.). Retrieved June 19, 2020, from https://www.astm.org/Standards/D1763.htm

Atif, R., Shyha, I., & Inam, F. (2016). Mechanical, thermal, and electrical properties of graphene-epoxy nanocomposites-A review. *Polymers*, *8*(8). https://doi.org/10.3390/polym8080281

Azeez, A. A., Rhee, K. Y., Park, S. J., & Hui, D. (2013). Epoxy clay nanocomposites - Processing, properties and applications: A review. *Composites Part B: Engineering*, *45*(1), 308–320. https://doi.org/10.1016/j.compositesb.2012.04.012

Balandin, A. A., Ghosh, S., Bao, W., Calizo, I., Teweldebrhan, D., Miao, F., & Lau, C. N. (2008). Superior thermal conductivity of single-layer graphene. *Nano Letters*, *8*(3), 902–907. https://doi.org/10.1021/nl0731872

Banerjee, S., Lee, J. H., Kuila, T., & Kim, N. H. (2015). Synthesis of graphene-based polymeric nanocomposites. In *Fillers and Reinforcements for Advanced Nanocomposites* (pp. 133–155). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-100079-3.00007-7

Bao, C., Guo, Y., Song, L., Kan, Y., Qian, X., & Hu, Y. (2011). In situ preparation of functionalized graphene oxide/epoxy nanocomposites with effective reinforcements. *Journal of Materials Chemistry*, *21*(35), 13290–13298. https://doi.org/10.1039/c1jm11434d

Bao, C., Song, L., Xing, W., Yuan, B., Wilkie, C. A., Huang, J., Guo, Y., & Hu, Y. (2012). Preparation of graphene by pressurized oxidation and multiplex reduction and its polymer nanocomposites by masterbatch-based melt blending. *Journal of Materials Chemistry*, *22*(13), 6088–6096. https://doi.org/10.1039/c2jm16203b

Baroncini, E. A., Kumar Yadav, S., Palmese, G. R., & Stanzione, J. F. (2016). Recent advances in bio-based epoxy resins and bio-based epoxy curing agents. In *Journal of Applied Polymer Science* (Vol. 133, Issue 45). John Wiley and Sons Inc. https://doi.org/10.1002/app.44103

Basu, S., & Bhattacharyya, P. (2012). Recent developments on graphene and graphene oxide based solid state gas sensors. *Sensors and Actuators, B: Chemical*, *173*, 1–21. https://doi.org/10.1016/j.snb.2012.07.092

Bautkinová, T., Sifton, A., Kutorglo, E. M., Dendisová, M., Kopecký, D., Ulbrich, P., Mazúr, P., Laachachi, A., & Hassouna, F. (2020). New approach for the development of reduced graphene oxide/polyaniline nanocomposites via sacrificial surfactant-stabilized reduced graphene oxide. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *589*, 124415. https://doi.org/10.1016/j.colsurfa.2020.124415

Becerril, H. A., Mao, J., Liu, Z., Stoltenberg, R. M., Bao, Z., & Chen, Y. (2008). Evaluation of solution-processed reduced graphene oxide films as transparent conductors. *ACS Nano*, *2*(3), 463–470. https://doi.org/10.1021/nn700375n

Berhanuddin, N. I. C., Zaman, I., Rozlan, S. A. M., Karim, M. A. A., Manshoor, B., Khalid, A., Chan, S. W., & Meng, Q. (2017). Enhancement of mechanical properties of epoxy/graphene nanocomposite. *Journal of Physics: Conference Series*, *914*(1), 012036. https://doi.org/10.1088/1742-6596/914/1/012036

Biercuk, M. J., Llaguno, M. C., Radosavljevic, M., Hyun, J. K., Johnson, A. T., & Fischer, J. E. (2002). Carbon nanotube composites for thermal management. *Applied Physics Letters*, *80*(15), 2767–2769. https://doi.org/10.1063/1.1469696

Bindu, B. S., Nair, A. B., Abraham, B. T., Beegum, P. M. S., & Thachil, E. T. (2014). Microwave exfoliated reduced graphene oxide epoxy nanocomposites for high performance applications. *Polymer*, *55*(16), 3614–3627. https://doi.org/10.1016/j.polymer.2014.05.032

Bourchak, M., Nahas, M. N., Kada, B., Khan, A. N., Al-Garni, A., & Juhany, K. A. (2019). Tensile Properties of Graphene-Based Nanocomposites: a Comparative Study of Ultrasonication and Microcompounding Processing Methods. *Mechanics of Composite Materials*, *55*(5), 617–626. https://doi.org/10.1007/s11029-019-09838-5

Cai, D., Yusoh, K., & Song, M. (2009). The mechanical properties and morphology of a graphite oxide nanoplatelet/polyurethane composite. *Nanotechnology*, *20*(8). https://doi.org/10.1088/0957-4484/20/8/085712

Camargo, P. H. C., Satyanarayana, K. G., & Wypych, F. (2009). Nanocomposites: Synthesis, structure, properties and new application opportunities. *Materials Research*, *12*(1), 1–39. https://doi.org/10.1590/S1516-14392009000100002

Campbell, F. (2010). *Structural Composite Materials. ASM International.* 612. https://books.google.co.uk/books?hl=en&lr=&id=D3Wta8e07t0C&oi=fnd&pg=PR1&dq=Structural+Composite+Materials+Copyright+©+2010,+ASM+International®+F.C.+Campbell+All+rights+reserved.&ots=T__g8yZ7sb&sig=a5MkkXLhycx-NEf4y6uHTQ6UDpg%0Ahttp://app.knovel.com/hotli

Chatterjee, S., Wang, J. W., Kuo, W. S., Tai, N. H., Salzmann, C., Li, W. L., Hollertz, R., Nüesch, F. A., & Chu, B. T. T. (2012). Mechanical reinforcement and thermal conductivity in expanded graphene nanoplatelets reinforced epoxy composites. *Chemical Physics Letters*, *531*, 6–10. https://doi.org/10.1016/j.cplett.2012.02.006

Chen, Y., Qi, Y., Tai, Z., Yan, X., Zhu, F., & Xue, Q. (2012). Preparation, mechanical properties and biocompatibility of graphene oxide/ultrahigh molecular weight polyethylene composites. *European Polymer Journal*, *48*(6), 1026–1033. https://doi.org/10.1016/j.eurpolymj.2012.03.011

Choi, Y. K., Sugimoto, K. I., Song, S. M., Gotoh, Y., Ohkoshi, Y., & Endo, M. (2005). Mechanical and physical properties of epoxy composites reinforced by vapor grown carbon nanofibers. *Carbon*, *43*(10), 2199–2208. https://doi.org/10.1016/j.carbon.2005.03.036

Chua, C. K., & Pumera, M. (2014). Chemical reduction of graphene oxide: A synthetic chemistry viewpoint. In *Chemical Society Reviews* (Vol. 43, Issue 1, pp. 291–312). Royal Society of Chemistry. https://doi.org/10.1039/c3cs60303b

Compton, O. C., Jain, B., Dikin, D. A., Abouimrane, A., Amine, K., & Nguyen, S. T. (2011). Chemically active reduced graphene oxide with tunable C/O ratios. *ACS Nano*, *5*(6), 4380–4391. https://doi.org/10.1021/nn1030725

Dato, A., & Frenklach, M. (2010). Substrate-free microwave synthesis of graphene: experimental conditions and hydrocarbon precursors. *New Journal of Physics*, *12*(12), 125013. https://doi.org/10.1088/1367-2630/12/12/125013

De C. Fim, F., Basso, N. R. S., Graebin, A. P., Azambuja, D. S., & Galland, G. B. (2013). Thermal, electrical, and mechanical properties of polyethylene-graphene nanocomposites obtained by in situ polymerization. *Journal of Applied Polymer Science*, *128*(5), 2630–2637. https://doi.org/10.1002/app.38317

Dhand, V., Rhee, K. Y., Ju Kim, H., & Ho Jung, D. (2013). A comprehensive review of graphene nanocomposites: Research status and trends. *Journal of Nanomaterials*, *2013*. https://doi.org/10.1155/2013/763953

Dimiev, A. M., Khannanov, A., Vakhitov, I., Kiiamov, A., Shukhina, K., & Tour, J. M. (2018). Revisiting the Mechanism of Oxidative Unzipping of Multiwall Carbon Nanotubes to Graphene Nanoribbons. *ACS Nano*, *12*(4), 3985–3993. https://doi.org/10.1021/acsnano.8b01617

Ding, P., Su, S., Song, N., Tang, S., Liu, Y., & Shi, L. (2014). Highly thermal conductive composites with polyamide-6 covalently-grafted graphene by an in situ polymerization and thermal reduction process. *Carbon*, *66*, 576–584. https://doi.org/10.1016/j.carbon.2013.09.041

Duplock, E. J., Scheffler, M., & Lindan, P. J. D. (2004). Hallmark of perfect graphene. *Physical Review Letters*, *92*(22), 225502. https://doi.org/10.1103/PhysRevLett.92.225502

Eda, G., & Chhowalla, M. (2009). Graphene-based Composite Thin Films for Electronics. *Nano Letters*, *9*(2), 814–818. https://doi.org/10.1021/nl8035367

Eda, G., & Chhowalla, M. (2010). Chemically derived graphene oxide: Towards large-area thin-film electronics and optoelectronics. In *Advanced Materials* (Vol. 22, Issue 22, pp. 2392–2415). John Wiley & Sons, Ltd. https://doi.org/10.1002/adma.200903689

Edwards, R. S., & Coleman, K. S. (2013). Graphene synthesis: Relationship to applications. *Nanoscale*, *5*(1), 38–51. https://doi.org/10.1039/c2nr32629a

Emiru, T. F., & Ayele, D. W. (2017). Controlled synthesis, characterization and reduction of graphene oxide: A convenient method for large scale production. *Egyptian Journal of Basic and Applied Sciences*, *4*(1), 74–79. https://doi.org/10.1016/j.ejbas.2016.11.002

Emtsev, K. V., Bostwick, A., Horn, K., Jobst, J., Kellogg, G. L., Ley, L., McChesney, J. L., Ohta, T., Reshanov, S. A., Röhrl, J., Rotenberg, E., Schmid, A. K., Waldmann, D., Weber, H. B., & Seyller, T. (2009). Towards wafer-size graphene layers by atmospheric pressure graphitization of silicon carbide. *Nature Materials*, *8*(3), 203–207. https://doi.org/10.1038/nmat2382

Epoxy Resin: Types, Uses, Properties & Chemical Structure. (n.d.). Retrieved July 1, 2020, from https://omnexus.specialchem.com/selection-guide/epoxy-resins-a-to-z-technical-review-of-thermosetting-polymer

Fabbri, P., Bassoli, E., Bon, S. B., & Valentini, L. (2012). Preparation and characterization of poly (butylene terephthalate)/grapheme composites by in-situ polymerization of cyclic butylene terephthalate. *Polymer*, *53*(4), 897–902. https://doi.org/10.1016/j.polymer.2012.01.015

Fang, H., Zhao, Y., Zhang, Y., Ren, Y., & Bai, S. L. (2017). Three-Dimensional Graphene Foam-Filled Elastomer Composites with High Thermal and Mechanical Properties. *ACS Applied Materials and Interfaces*, *9*(31), 26447–26459. https://doi.org/10.1021/acsami.7b07650

Farajvand, M., Farajzadeh, K., & Faghani, G. (2018). Synthesis of graphene oxide/polyaniline nanocomposite for measuring cadmium(II) by solid phase extraction combined with dispersive liquid-liquid microextraction. *Materials Research Express*, *5*(7), 075017. https://doi.org/10.1088/2053-1591/aace3a

Ferreira, F. V., Cividanes, L. D. S., Brito, F. S., de Menezes, B. R. C., Franceschi, W., Simonetti, E. A. N., & Thim, G. P. (2016). Functionalization of graphene and applications. In *SpringerBriefs in Applied Sciences and Technology* (Issue 9783319351094, pp. 1–29). Springer Verlag. https://doi.org/10.1007/978-3-319-35110-0_1

Ferreira, F. V., Brito, F. S., Franceschi, W., Simonetti, E. A. N., Cividanes, L. S., Chipara, M., & Lozano, K. (2018). Functionalized graphene oxide as reinforcement in epoxy based nanocomposites. *Surfaces and Interfaces*, *10*(December 2017), 100–109. https://doi.org/10.1016/j.surfin.2017.12.004

GA, K. (2019). Enriched Mechanical Properties of Epoxy/Coir Fiber Composites with Graphene Oxide. *Research & Development in Material Science*, *10*(5). https://doi.org/10.31031/rdms.2019.10.000749

Gadipelli, S., & Guo, Z. X. (2015). Graphene-based materials: Synthesis and gas sorption, storage and separation. In *Progress in Materials Science* (Vol. 69, pp. 1–60). Elsevier Ltd. https://doi.org/10.1016/j.pmatsci.2014.10.004

Galpaya, D., Wang, M., Liu, M., Motta, N., Waclawik, E., & Yan, C. (2012). Recent Advances in Fabrication and Characterization of Graphene-Polymer Nanocomposites. *Graphene*, *01*(02), 30–49. https://doi.org/10.4236/graphene.2012.12005

Ganguli, S., Roy, A. K., & Anderson, D. P. (2008). Improved thermal conductivity for chemically functionalized exfoliated graphite/epoxy composites. *Carbon*, *46*(5), 806–817. https://doi.org/10.1016/j.carbon.2008.02.008

Ghasemi-Kahrizsangi, A., Neshati, J., Shariatpanahi, H., & Akbarinezhad, E. (2015). Effect of SDS modification of carbon black nanoparticles on corrosion protection behavior of epoxy nanocomposite coatings. *Polymer Bulletin*, *72*(9), 2297–2310. https://doi.org/10.1007/s00289-015-1406-4

Guadagno, L., Raimondo, M., Vittoria, V., Vertuccio, L., Naddeo, C., Russo, S., De Vivo, B., Lamberti, P., Spinelli, G., & Tucci, V. (2014). Development of epoxy mixtures for application in aeronautics and aerospace. *RSC Advances*, *4*(30), 15474–15488. https://doi.org/10.1039/c3ra48031c

Guan, L. Z., Zhao, L., Wan, Y. J., & Tang, L. C. (2018). Three-dimensional graphene-based polymer nanocomposites: preparation, properties and applications. *Nanoscale*, *10*(31), 14788–14811. https://doi.org/10.1039/c8nr03044h

Gudarzi, M. M., & Sharif, F. (2012). Enhancement of dispersion and bonding of graphene-polymer through wet transfer of functionalized graphene oxide. *Express Polymer Letters*, *6*(12), 1017–1031. https://doi.org/10.3144/expresspolymlett.2012.107

Güler, Ö., Güler, S. H., Selen, V., Albayrak, M. G., & Evin, E. (2016). Production of graphene layer by liquid-phase exfoliation with low sonication power and sonication time from synthesized expanded graphite. *Fullerenes Nanotubes and Carbon Nanostructures*, *24*(2), 123–127. https://doi.org/10.1080/1536383X.2015.1114472

Guo, S., Lu, Y., Wan, X., Wu, F., Zhao, T., & Shen, C. (2020). Preparation, characterization of highly dispersed reduced graphene oxide/epoxy resin and its application in alkali-activated slag composites. *Cement and Concrete Composites*, *105*. https://doi.org/10.1016/j.cemconcomp.2019.103424

Gupta, S., & Meek, R. (2018). Metal nanoparticles-grafted functionalized graphene coated with nanostructured polyaniline 'hybrid' nanocomposites as high-performance biosensors. *Sensors and Actuators, B: Chemical*, *274*(May), 85–101. https://doi.org/10.1016/j.snb.2018.07.131

Haar, S., Bruna, M., Lian, J. X., Tomarchio, F., Olivier, Y., Mazzaro, R., Morandi, V., Moran, J., Ferrari, A. C., Beljonne, D., Ciesielski, A., & Samorì, P. (2016). Liquid-Phase Exfoliation of Graphite into Single- and Few-Layer Graphene with α-Functionalized Alkanes. *Journal of Physical Chemistry Letters*, *7*(14), 2714–2721. https://doi.org/10.1021/acs.jpclett.6b01260

Hayyan, M., Abo-Hamad, A., AlSaadi, M. A. H., & Hashim, M. A. (2015). Functionalization of graphene using deep eutectic solvents. *Nanoscale Research Letters*, *10*(1). https://doi.org/10.1186/s11671-015-1004-2

He, H., Klinowski, J., Forster, M., & Lerf, A. (1998). A new structural model for graphite oxide. *Chemical Physics Letters*, *287*(1–2), 53–56. https://doi.org/10.1016/S0009-2614(98)00144-4

Ho, M. W., Lam, C. K., Lau, K. tak, Ng, D. H. L., & Hui, D. (2006). Mechanical properties of epoxy-based composites using nanoclays. *Composite Structures*, *75*(1–4), 415–421. https://doi.org/10.1016/j.compstruct.2006.04.051

Hu, H., Wang, X., Wang, J., Wan, L., Liu, F., Zheng, H., Chen, R., & Xu, C. (2010). Preparation and properties of graphene nanosheets-polystyrene nanocomposites via in situ emulsion polymerization. *Chemical Physics Letters*, *484*(4–6), 247–253. https://doi.org/10.1016/j.cplett.2009.11.024

Hu, K., Kulkarni, D. D., Choi, I., & Tsukruk, V. V. (2014). Graphene-polymer nanocomposites for structural and functional applications. In *Progress in Polymer Science* (Vol. 39, Issue 11, pp. 1934–1972). Elsevier Ltd. https://doi.org/10.1016/j.progpolymsci.2014.03.001

Huang, H., Chen, S., Wee, A. T. S., & Chen, W. (2014). Epitaxial growth of graphene on silicon carbide (SiC). In *Graphene: Properties, Preparation, Characterisation and Devices* (pp. 3–26). Elsevier Ltd. https://doi.org/10.1533/9780857099334.1.3

Huang, Haowei, Tian, Y., Xie, Y., Mo, R., Hu, J., Li, M., Sheng, X., Jiang, X., & Zhang, X. (2020). Modification of graphene oxide with acrylate phosphorus monomer via thiol-Michael addition click reaction to enhance the anti-corrosive performance of waterborne epoxy coatings. *Progress in Organic Coatings*, *146*(March), 105724. https://doi.org/10.1016/j.porgcoat.2020.105724

Huang, X., Qi, X., Boey, F., & Zhang, H. (2012). Graphene-based composites. *Chemical Society Reviews*, *41*(2), 666–686. https://doi.org/10.1039/c1cs15078b

Hussain, F., Hojjati, M., Okamoto, M., & Gorga, R. E. (2006). Review article: Polymer-matrix nanocomposites, processing, manufacturing, and application: An overview. *Journal of Composite Materials*, *40*(17), 1511–1575. https://doi.org/10.1177/0021998306067321

Im, H., & Kim, J. (2012). Thermal conductivity of a graphene oxide-carbon nanotube hybrid/epoxy composite. *Carbon*, *50*(15), 5429–5440. https://doi.org/10.1016/j.carbon.2012.07.029

Imran, K. A., & Shivakumar, K. N. (2019). Graphene-modified carbon/epoxy nanocomposites: Electrical, thermal and mechanical properties. *Journal of Composite Materials*, *53*(1), 93–106. https://doi.org/10.1177/0021998318780468

Inam, F. (2014). Epoxy - the hub for the most versatile polymer with exceptional combination of superlative features. *Epoxy*, *1*(1), 1–2. https://doi.org/10.2478/epoxy-2014-0001

Jacobberger, R. M., Machhi, R., Wroblewski, J., Taylor, B., Gillian-Daniel, A. L., & Arnold, M. S. (2015). Simple Graphene Synthesis via Chemical Vapor Deposition. *Journal of Chemical Education*, *92*(11), 1903–1907. https://doi.org/10.1021/acs.jchemed.5b00126

Jiat, X., Yan, B., Hiew, Z., Chiew, K., Yee, L., Gan, S., Thangalazhy-gopakumar, S., & Rigby, S. (2018). Review on graphene and its derivatives : Synthesis methods and potential industrial implementation. *Journal of the Taiwan Institute of Chemical Engineers*, *xxxx*. https://doi.org/10.1016/j.jtice.2018.10.028

Jin, F. L., Li, X., & Park, S. J. (2015). Synthesis and application of epoxy resins: A review. *Journal of Industrial and Engineering Chemistry*, *29*, 1–11. https://doi.org/10.1016/j.jiec.2015.03.026

Jung, J., & Sodano, H. A. (2020). High strength epoxy nanocomposites reinforced by epoxy functionalized aramid nanofibers. *Polymer*, *195*, 122438. https://doi.org/10.1016/j.polymer.2020.122438

Kalali, E. N., Guo, W., Wang, X., Xing, W., Song, L., & Hu, Y. (2020). Effect of metal-based nanoparticles decorated graphene hybrids on flammability of epoxy nanocomposites. *Composites Part A: Applied Science and Manufacturing*, *129*, 105694. https://doi.org/10.1016/j.compositesa.2019.105694

Keyte, J., Pancholi, K., & Njuguna, J. (2019). Recent Developments in Graphene Oxide/Epoxy Carbon Fiber-Reinforced Composites. *Frontiers in Materials*, *6*(October), 1–30. https://doi.org/10.3389/fmats.2019.00224

Kiew, S. F., Kiew, L. V., Lee, H. B., Imae, T., & Chung, L. Y. (2016). Assessing biocompatibility of graphene oxide-based nanocarriers: A review. In *Journal of Controlled Release* (Vol. 226, pp. 217–228). Elsevier B.V. https://doi.org/10.1016/j.jconrel.2016.02.015

Kilic, U., Sherif, M. M., & Ozbulut, O. E. (2019). Tensile properties of graphene nanoplatelets/epoxy composites fabricated by various dispersion techniques. *Polymer Testing*, *76*(March), 181–191. https://doi.org/10.1016/j.polymertesting.2019.03.028

Kim, B. W., & Mayer, A. H. (2003). Influence of fiber direction and mixed-mode ration on delamination fracture toughness of carbon/epoxy laminates. *Composites Science and Technology*, *63*(5), 695–713. https://doi.org/10.1016/S0266-3538(02)00258-0

Kim, H., Abdala, A. A., & MacOsko, C. W. (2010). Graphene/polymer nanocomposites. In *Macromolecules* (Vol. 43, Issue 16, pp. 6515–6530). https://doi.org/10.1021/ma100572e

Kim, H., Kobayashi, S., Abdurrahim, M. A., Zhang, M. J., Khusainova, A., Hillmyer, M. A., Abdala, A. A., & MacOsko, C. W. (2011). Graphene/polyethylene nanocomposites: Effect of polyethylene functionalization and blending methods. *Polymer*, *52*(8), 1837–1846. https://doi.org/10.1016/j.polymer.2011.02.017

Kim, H., & Macosko, C. W. (2009). Processing-property relationships of polycarbonate/graphene composites. *Polymer*, *50*(15), 3797–3809. https://doi.org/10.1016/j.polymer.2009.05.038

Kim, H., Miura, Y., & MacOsko, C. W. (2010). Graphene/polyurethane nanocomposites for improved gas barrier and electrical conductivity. *Chemistry of Materials*, *22*(11), 3441–3450. https://doi.org/10.1021/cm100477v

Kuila, T., Bose, S., Mishra, A. K., Khanra, P., Kim, N. H., & Lee, J. H. (2012). Effect of functionalized graphene on the physical properties of linear low density polyethylene nanocomposites. *Polymer Testing*, *31*(1), 31–38. https://doi.org/10.1016/j.polymertesting.2011.09.007

Kuilla, T., Bhadra, S., Yao, D., Kim, N. H., Bose, S., & Lee, J. H. (2010). Recent advances in graphene based polymer composites. In *Progress in Polymer Science (Oxford)* (Vol. 35, Issue 11, pp. 1350–1375). Elsevier Ltd. https://doi.org/10.1016/j.progpolymsci.2010.07.005

Kumar, A. (2018). Review A review of the mechanical and thermal properties of graphene and its hybrid polymer nanocomposites for structural applications. *Journal of Materials Science*. https://doi.org/10.1007/s10853-018-03244-3

Kumar, S., Samal, S. K., Mohanty, S., & Nayak, S. K. (2018). Recent Development of Biobased Epoxy Resins: A Review. In *Polymer - Plastics Technology and Engineering* (Vol. 57, Issue 3, pp. 133–155). Taylor and Francis Inc. https://doi.org/10.1080/03602559.2016.1253742

Lawal, A. T. (2019). Graphene-based nano composites and their applications. A review. In *Biosensors and Bioelectronics* (Vol. 141, p. 111384). Elsevier Ltd. https://doi.org/10.1016/j.bios.2019.111384

Layek, R. K., Samanta, S., & Nandi, A. K. (2012). The physical properties of sulfonated graphene/poly(vinyl alcohol) composites. *Carbon*, *50*(3), 815–827. https://doi.org/10.1016/j.carbon.2011.09.039

Lee, C., Wei, X., Kysar, J. W., & Hone, J. (2008). Measurement of the elastic properties and intrinsic strength of monolayer graphene. *Science*, *321*(5887), 385–388. https://doi.org/10.1126/science.1157996

Li, B., Wang, X., Bai, M., & Shen, Y. (2020). Improvement of curing reaction activity of one-component room temperature-curable epoxy adhesive by the addition of functionalized graphene oxide. *International Journal of Adhesion and Adhesives*, *98*, 102537. https://doi.org/10.1016/j.ijadhadh.2019.102537

Li, W., Song, B., Zhang, S., Zhang, F., Liu, C., Zhang, N., Yao, H., & Shi, Y. (2020). Using 3-Isocyanatopropyltrimethoxysilane to Decorate Graphene Oxide with Nano-Titanium Dioxide for Enhancing the Anti-Corrosion Properties of Epoxy Coating. *Polymers*, *12*(4), 837. https://doi.org/10.3390/polym12040837

Li, X., & McKenna, G. B. (2012). Considering viscoelastic micromechanics for the reinforcement of graphene polymer nanocomposites. *ACS Macro Letters*, *1*(3), 388–391. https://doi.org/10.1021/mz200253x

Li, X., Mckenna, G. B., Miquelard-Garnier, G., Guinault, A., Sollogoub, C., Regnier, G., & Rozanski, A. (2014). Forced assembly by multilayer coextrusion to create oriented graphene reinforced polymer nanocomposites. *Polymer*, *55*(1), 248–257. https://doi.org/10.1016/j.polymer.2013.11.025

Li, Yan, Zhang, H., Porwal, H., Huang, Z., Bilotti, E., & Peijs, T. (2017). Mechanical, electrical and thermal properties of in-situ exfoliated graphene/epoxy nanocomposites. *Composites Part A: Applied Science and Manufacturing*, *95*, 229–236. https://doi.org/10.1016/j.compositesa.2017.01.007

Li, Yi, Xiao, F., & Wong, C. P. (2007). Novel, environmentally friendly crosslinking system of an epoxy using an amino acid: Tryptophan-cured diglycidyl ether of bisphenol A epoxy. *Journal of Polymer Science Part A: Polymer Chemistry*, *45*(2), 181–190. https://doi.org/10.1002/pola.21742

Liang, J., Huang, Y., Zhang, L., Wang, Y., Ma, Y., Cuo, T., & Chen, Y. (2009). Molecular-level dispersion of graphene into poly(vinyl alcohol) and effective reinforcement of their nanocomposites. *Advanced Functional Materials*, *19*(14), 2297–2302. https://doi.org/10.1002/adfm.200801776

Lin, W., Zhang, R., & Wong, C. P. (2010). Modeling of thermal conductivity of graphite nanosheet composites. *Journal of Electronic Materials*, *39*(3), 268–272. https://doi.org/10.1007/s11664-009-1062-2

Luo, B., & Zhi, L. (2015). Design and construction of three dimensional graphene-based composites for lithium ion battery applications. *Energy and Environmental Science*, *8*(2), 456–477. https://doi.org/10.1039/c4ee02578d

Mahmoud, W. E. (2011). Morphology and physical properties of poly(ethylene oxide) loaded graphene nanocomposites prepared by two different techniques. *European Polymer Journal*, *47*(8), 1534–1540. https://doi.org/10.1016/j.eurpolymj.2011.05.011

Maio, A., Fucarino, R., Khatibi, R., Rosselli, S., Bruno, M., & Scaffaro, R. (2015). A novel approach to prevent graphene oxide re-aggregation during the melt compounding with polymers. *Composites Science and Technology*, *119*, 131–137. https://doi.org/10.1016/j.compscitech.2015.10.006

McAllister, M. J., Li, J. L., Adamson, D. H., Schniepp, H. C., Abdala, A. A., Liu, J., Herrera-Alonso, M., Milius, D. L., Car, R., Prud'homme, R. K., & Aksay, I. A. (2007). Single sheet functionalized graphene by oxidation and thermal expansion of graphite. *Chemistry of Materials*, *19*(18), 4396–4404. https://doi.org/10.1021/cm0630800

Meng, Q., Han, S., Araby, S., Zhao, Y., Liu, Z., & Lu, S. (2019). Mechanically robust, electrically and thermally conductive graphene-based epoxy adhesives. *Journal of Adhesion Science and Technology*, *33*(12), 1337–1356. https://doi.org/10.1080/01694243.2019.1595890

Meschi Amoli, B., Trinidad, J., Rivers, G., Sy, S., Russo, P., Yu, A., Zhou, N. Y., & Zhao, B. (2015). SDS-stabilized graphene nanosheets for highly electrically conductive adhesives. *Carbon*, *91*, 188–199. https://doi.org/10.1016/j.carbon.2015.04.039

Milani, M. A., González, D., Quijada, R., Basso, N. R. S., Cerrada, M. L., Azambuja, D. S., & Galland, G. B. (2013). Polypropylene/graphene nanosheet nanocomposites by in situ polymerization: Synthesis, characterization and fundamental properties. *Composites Science and Technology*, *84*, 1–7. https://doi.org/10.1016/j.compscitech.2013.05.001

Mittal, G., Dhand, V., Rhee, K. Y., Park, S. J., & Lee, W. R. (2015). A review on carbon nanotubes and graphene as fillers in reinforced polymer nanocomposites. *Journal of Industrial and Engineering Chemistry*, *21*, 11–25. https://doi.org/10.1016/j.jiec.2014.03.022

Mohan, V. B., Lau, K. tak, Hui, D., & Bhattacharyya, D. (2018). Graphene-based materials and their composites: A review on production, applications and product limitations. *Composites Part B: Engineering*, *142*(December 2017), 200–220. https://doi.org/10.1016/j.compositesb.2018.01.013

Moosa, A. A., Kubba, F., Raad, M., & S.A, A. R. (2016). Mechanical and Thermal Properties of Graphene Nanoplates and Functionalized Carbon-Nanotubes Hybrid Epoxy Nanocomposites. *American Journal of Materials Science*, *6*(5), 125–134. https://doi.org/10.5923/j.materials.20160605.02

Naebe, M., Wang, J., Amini, A., Khayyam, H., Hameed, N., Li, L. H., Chen, Y., & Fox, B. (2014). Mechanical Property and Structure of Covalent Functionalised Graphene/Epoxy Nanocomposites. *Scientific Reports*, *4*(1), 1–7. https://doi.org/10.1038/srep04375

Nanocomposites, P., & Tarfaoui, M. (2018). *Effect of Graphene Nano-Additives on the Local Mechanical Behavior of Derived*. https://doi.org/10.3390/polym10060667

Nihtianov, S., Tan, Z., & George, B. (2017). New Trends in Smart Sensors for Industrial Applications-Part II. In *IEEE Transactions on Industrial Electronics* (Vol. 64, Issue 12, pp. 9592–9594). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/TIE.2017.2758038

Novoselov, K. S., Fal'Ko, V. I., Colombo, L., Gellert, P. R., Schwab, M. G., & Kim, K. (2012). A roadmap for graphene. In *Nature* (Vol. 490, Issue 7419, pp. 192–200). Nature Publishing Group. https://doi.org/10.1038/nature11458

Novoselov, K. S., Geim, A. K., Morozov, S. V., Jiang, D., Zhang, Y., Dubonos, S. V., Grigorieva, I. V., & Firsov, A. A. (2004). Electric field in atomically thin carbon films. *Science*, *306*(5696), 666–669. https://doi.org/10.1126/science.1102896

Oh, H., Kim, K., Ryu, S., & Kim, J. (2019). Enhancement of thermal conductivity of polymethyl methacrylate-coated graphene/epoxy composites using admicellar polymerization with different ionic surfactants. *Composites Part A: Applied Science and Manufacturing*, *116*, 206–215. https://doi.org/10.1016/j.compositesa.2018.10.035

Papageorgiou, D. G., Kinloch, I. A., & Young, R. J. (2017). Mechanical properties of graphene and graphene-based nanocomposites. *Progress in Materials Science*, *90*, 75–127. https://doi.org/10.1016/j.pmatsci.2017.07.004

Papageorgiou, D. G., Tzounis, L., Papageorgiou, G. Z., Bikiaris, D. N., & Chrissafis, K. (2014). β-nucleated propylene-ethylene random copolymer filled with multi-walled carbon nanotubes: Mechanical, thermal and rheological properties. *Polymer*, *55*(16), 3758–3769. https://doi.org/10.1016/j.polymer.2014.06.012

Park, C. H., Lee, S. W., Park, J. W., & Kim, H. J. (2013). Preparation and characterization of dual curable adhesives containing epoxy and acrylate functionalities. *Reactive and Functional Polymers*, *73*(4), 641–646. https://doi.org/10.1016/j.reactfunctpolym.2013.01.012

Pathak, A. K., Borah, M., Gupta, A., Yokozeki, T., & Dhakate, S. R. (2016). Improved mechanical properties of carbon fiber/graphene oxide-epoxy hybrid composites. *Composites Science and Technology*, *135*, 28–38. https://doi.org/10.1016/j.compscitech.2016.09.007

Paul, D. R., & Robeson, L. M. (2008). Polymer nanotechnology: Nanocomposites. *Polymer*, *49*(15), 3187–3204. https://doi.org/10.1016/j.polymer.2008.04.017

Pham, V. H., Ha, Y. W., Kim, S. H., Jeong, H. T., Jung, M. Y., Ko, B. S., Hwang, Y. J., & Chung, J. S. (2014). Synthesis of epoxy encapsulated organoclay nanocomposite latex via phase inversion emulsification and its gas barrier property. *Journal of Industrial and Engineering Chemistry*, *20*(1), 108–112. https://doi.org/10.1016/j.jiec.2013.04.019

Pokharel, P., Truong, Q. T., & Lee, D. S. (2014). Multi-step microwave reduction of graphite oxide and its use in the formation of electrically conductive graphene/epoxy composites. *Composites Part B: Engineering*, *64*, 187–193. https://doi.org/10.1016/j.compositesb.2014.04.013

Potts, J. R., Lee, S. H., Alam, T. M., An, J., Stoller, M. D., Piner, R. D., & Ruoff, R. S. (2011). Thermomechanical properties of chemically modified graphene/poly(methyl methacrylate) composites made by in situ polymerization. *Carbon*, *49*(8), 2615–2623. https://doi.org/10.1016/j.carbon.2011.02.023

Prolongo, S. G., Jiménez-Suárez, A., Moriche, R., & Ureña, A. (2014). Graphene nanoplatelets thickness and lateral size influence on the morphology and behavior of epoxy composites. *European Polymer Journal*, *53*(1), 292–301. https://doi.org/10.1016/j.eurpolymj.2014.01.019

Prolongo, S. G., Moriche, R., Jiménez-Suárez, A., Sánchez, M., & Ureña, A. (2014). Epoxy adhesives modified with graphene for thermal interface materials. *Journal of Adhesion*, *90*(10), 835–847. https://doi.org/10.1080/00218464.2014.893510

Qian, X., Song, L., Tai, Q., Hu, Y., & Yuen, R. K. K. (2013). Graphite oxide/polyurea and graphene/polyurea nanocomposites: A comparative investigation on properties reinforcements and mechanism. *Composites Science and Technology*, *74*, 228–234. https://doi.org/10.1016/j.compscitech.2012.11.018

Rahnamol, A. M., & Gopalakrishnan, J. (2020). Improved dielectric and dynamic mechanical properties of epoxy/polyaniline nanorod/in situ reduced graphene oxide hybrid nanocomposites. *Polymer Composites*, *March*, 1–16. https://doi.org/10.1002/pc.25592

Ramanathan, T., Abdala, A. A., Stankovich, S., Dikin, D. A., Herrera-Alonso, M., Piner, R. D., Adamson, D. H., Schniepp, H. C., Chen, X., Ruoff, R. S., Nguyen, S. T., Aksay, I. A., Prud'Homme, R. K., & Brinson, L. C. (2008). Functionalized graphene sheets for polymer nanocomposites. *Nature Nanotechnology*, *3*(6), 327–331. https://doi.org/10.1038/nnano.2008.96

Ratna, D. (2003). Modification of epoxy resins for improvement of adhesion: A critical review. *Journal of Adhesion Science and Technology*, *17*(12), 1655–1668. https://doi.org/10.1163/156856103322396721

Rohini, R., Katti, P., & Bose, S. (2015). Tailoring the interface in graphene/thermoset polymer composites: A critical review. *Polymer*, *70*, A17–A34. https://doi.org/10.1016/J.POLYMER.2015.06.016

Saadatmandi, S., Asghari, M., & Ramezanzadeh, B. (2019). Effective epoxy composite coating mechanical/fracture toughness properties improvement by incorporation of graphene oxide nano-platforms reduced by a green/biocompataible reductant. *Journal of Industrial and Engineering Chemistry*, *75*, 271–284. https://doi.org/10.1016/j.jiec.2019.03.038

Sadasivuni, K. K., Ponnamma, D., Thomas, S., & Grohens, Y. (2014). Evolution from graphite to graphene elastomer composites. In *Progress in Polymer Science* (Vol. 39, Issue 4, pp. 749–780). Elsevier Ltd. https://doi.org/10.1016/j.progpolymsci.2013.08.003

Saha, P., Pyne, D. K., Ghosh, S., Banerjee, S., Das, S., Ghosh, S., Dutta, P., & Halder, A. (2018). Effect of an anionic surfactant (SDS) on the photoluminescence of graphene oxide (GO) in acidic and alkaline medium. *RSC Advances*, *8*(1), 584–595. https://doi.org/10.1039/c7ra12024a

Saharudin, M. S., Hasbi, S., Okolo, C., Wei, J., & Rahim Jusoh, A. B. (2019). The processing of epoxy/multi-layer graphene nanocomposites: Effects of acetone on properties. *Journal of Engineering Science and Technology*, *14*(6), 3131–3142.

Sahoo, B. P., & Tripathy, D. K. (2017). Properties and applications of polymer nanocomposites: Clay and carbon based polymer nanocomposites. *Properties and Applications of Polymer Nanocomposites: Clay and Carbon Based Polymer Nanocomposites*, 1–222. https://doi.org/10.1007/978-3-662-53517-2

Salimikia, I., Heydari, R., & Yazdankhah, F. (2018). Polyaniline/graphene oxide nanocomposite as a sorbent for extraction and determination of nicotine using headspace solid-phase microextraction and gas chromatography–flame ionization detector. *Journal of the Iranian Chemical Society*, *15*(7), 1593–1601. https://doi.org/10.1007/s13738-018-1357-4

Saravanan, N., Rajasekar, R., Mahalakshmi, S., Sathishkumar, T. P., Sasikumar, K., & Sahoo, S. (2014). Graphene and modified graphene-based polymer nanocomposites - A review. *Journal of Reinforced Plastics and Composites*, *33*(12), 1158–1170. https://doi.org/10.1177/0731684414524847

Seyedin, M. Z., Razal, J. M., Innis, P. C., Jalili, R., & Wallace, G. G. (2015). Achieving Outstanding Mechanical Performance in Reinforced Elastomeric Composite Fibers Using Large Sheets of Graphene Oxide. *Advanced Functional Materials*, *25*(1), 94–104. https://doi.org/10.1002/adfm.201402167

Shamsuddoha, M., Islam, M. M., Aravinthan, T., Manalo, A., & Lau, K. tak. (2013). Characterisation of mechanical and thermal properties of epoxy grouts for composite repair of steel pipelines. *Materials and Design*, *52*, 315–327. https://doi.org/10.1016/j.matdes.2013.05.068

Sharma, B., Malik, P., & Jain, P. (2018). Biopolymer reinforced nanocomposites: A comprehensive review. In *Materials Today Communications* (Vol. 16, pp. 353–363). Elsevier Ltd. https://doi.org/10.1016/j.mtcomm.2018.07.004

Shearer, C. J., Slattery, A. D., Stapleton, A. J., Shapter, J. G., & Gibson, C. T. (2016). Accurate thickness measurement of graphene. *Nanotechnology*, *27*(12), 0. https://doi.org/10.1088/0957-4484/27/12/125704

Shen, M. Y., Chang, T. Y., Hsieh, T. H., Li, Y. L., Chiang, C. L., Yang, H., & Yip, M. C. (2013). Mechanical properties and tensile fatigue of graphene nanoplatelets reinforced polymer nanocomposites. *Journal of Nanomaterials*, *2013*. https://doi.org/10.1155/2013/565401

Singh, V., Joung, D., Zhai, L., Das, S., Khondaker, S. I., & Seal, S. (2011). Graphene based materials: Past, present and future. *Progress in Materials Science*, *56*(8), 1178–1271. https://doi.org/10.1016/j.pmatsci.2011.03.003

Son, M., & Ham, M. H. (2017). Low-temperature synthesis of graphene by chemical vapor deposition and its applications. *FlatChem*, *5*(July), 40–49. https://doi.org/10.1016/j.flatc.2017.07.002

Stankovich, S., Dikin, D. A., Dommett, G. H. B., Kohlhaas, K. M., Zimney, E. J., Stach, E. A., Piner, R. D., Nguyen, S. B. T., & Ruoff, R. S. (2006). Graphene-based composite materials. *Nature*, *442*(7100), 282–286. https://doi.org/10.1038/nature04969

Stankovich, S., Piner, R. D., Nguyen, S. B. T., & Ruoff, R. S. (2006). Synthesis and exfoliation of isocyanate-treated graphene oxide nanoplatelets. *Carbon*, *44*(15), 3342–3347. https://doi.org/10.1016/j.carbon.2006.06.004

Tang, X., Zhou, Y., & Peng, M. (2016). Green Preparation of Epoxy/Graphene Oxide Nanocomposites Using a Glycidylamine Epoxy Resin as the Surface Modifier and Phase Transfer Agent of Graphene Oxide. *ACS Applied Materials and Interfaces*, *8*(3), 1854–1866. https://doi.org/10.1021/acsami.5b09830

Teh, P. L., Jaafar, M., Akil, H. M., Seetharamu, K. N., Wagiman, A. N. R., & Beh, K. S. (2008). Thermal and mechanical properties of particulate fillers filled epoxy composites for electronic packaging application. *Polymers for Advanced Technologies*, *19*(4), 308–315. https://doi.org/10.1002/pat.1014

Tesoro, G. (1988). Epoxy resins-chemistry and technology. *Journal of Polymer Science: Polymer Letters Edition*, *26*(12), 539–539. https://doi.org/10.1002/pol.1988.140261212

Thostenson, E. T., Li, C., & Chou, T. W. (2005). Nanocomposites in context. In *Composites Science and Technology* (Vol. 65, Issues 3–4, pp. 491–516). https://doi.org/10.1016/j.compscitech.2004.11.003

Tjong, S. C. (2013). Synthesis and Structural-Mechanical Property Characteristics of Graphene-Polymer Nanocomposites. In *Nanocrystalline Materials: Their Synthesis-Structure-Property Relationships and Applications* (Second Edi). Elsevier Ltd. https://doi.org/10.1016/B978-0-12-407796-6.00010-5

Tjong, S. C., Xu, S. A., Li, R. K. Y., & Mai, Y. W. (2002). Mechanical behavior and fracture toughness evaluation of maleic anhydride compatibilized short glass fiber/SEBS/polypropylene hybrid composites. *Composites Science and Technology*, *62*(6), 831–840. https://doi.org/10.1016/S0266-3538(02)00037-4

Tkach, A., Almeida, A., Levin, I., Woicik, J. C., & Vilarinho, P. M. (2021). Dielectric Relaxation, Local Structure and Lattice Dynamics in Mn-Doped Potassium Tantalate Ceramics. *Materials 2021, Vol. 14, Page 4632*, *14*(16), 4632. https://doi.org/10.3390/MA14164632

Unnikrishnan, K. P., & Thachil, E. T. (2006). Toughening of epoxy resins. *Designed Monomers and Polymers*, *9*(2), 129–152. https://doi.org/10.1163/156855506776382664

Vallés, C., Beckert, F., Burk, L., Mülhaupt, R., Young, R. J., & Kinloch, I. A. (2016). Effect of the C/O ratio in graphene oxide materials on the reinforcement of epoxy-based nanocomposites. *Journal of Polymer Science, Part B: Polymer Physics*, *54*(2), 281–291. https://doi.org/10.1002/polb.23925

Verdejo, R., Bernal, M. M., Romasanta, L. J., & Lopez-Manchado, M. A. (2011). Graphene filled polymer nanocomposites. *Journal of Materials Chemistry*, *21*(10), 3301–3310. https://doi.org/10.1039/c0jm02708a

Wan, Y. J., Tang, L. C., Gong, L. X., Yan, D., Li, Y. B., Wu, L. Bin, Jiang, J. X., & Lai, G. Q. (2014). Grafting of epoxy chains onto graphene oxide for epoxy composites with improved mechanical and thermal properties. *Carbon*, *69*, 467–480. https://doi.org/10.1016/j.carbon.2013.12.050

Wang, J. Y., Yang, S. Y., Huang, Y. L., Tien, H. W., Chin, W. K., & Ma, C. C. M. (2011). Preparation and properties of graphene oxide/polyimide composite films with low dielectric constant and ultrahigh strength via in situ polymerization. *Journal of Materials Chemistry*, *21*(35), 13569–13575. https://doi.org/10.1039/c1jm11766a

Wang, X., Hu, Y., Song, L., Yang, H., Xing, W., & Lu, H. (2011). In situ polymerization of graphene nanosheets and polyurethane with enhanced mechanical and thermal properties. *Journal of Materials Chemistry*, *21*(12), 4222–4227. https://doi.org/10.1039/c0jm03710a

Wei, J. (2017). *Graphene in epoxy system: Dispersion, preparation and reinforcement effect*. Northumbria University. http://nrl.northumbria.ac.uk/36264/

Wei, J., Atif, R., Vo, T., & Inam, F. (2015). Graphene Nanoplatelets in Epoxy System: Dispersion, Reaggregation, and Mechanical Properties of Nanocomposites. *Journal of Nanomaterials*, *2015*. https://doi.org/10.1155/2015/561742

Wei, J., & Inam, F. (2017). Processing of Epoxy / Graphene Nanocomposites : Effects of Surfactants. *Journal of Polymer Science & Applications*, 1–7.

Wei, J., Vo, T., & Inam, F. (2015). Epoxy/graphene nanocomposites - processing and properties: a review. *RSC Advances*, *5*(90), 73510–73524. https://doi.org/10.1039/c5ra13897c

Wu, X., Liu, Y., Yang, H., & Shi, Z. (2016). Large-scale synthesis of high-quality graphene sheets by an improved alternating current arc-discharge method. *RSC Advances*, *6*(95), 93119–93124. https://doi.org/10.1039/c6ra22273k

Xiang, Q., & Xiao, F. (2020). Applications of epoxy materials in pavement engineering. *Construction and Building Materials*, *235*, 117529. https://doi.org/10.1016/j.conbuildmat.2019.117529

Xie, Y., Liu, C., Liu, W., Liang, L., Wang, S., Zhang, F., Shi, H., & Yang, M. (2020). A novel approach to fabricate polyacrylate modified graphene oxide for improving the corrosion resistance of epoxy coatings. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *593*(December 2019), 124627. https://doi.org/10.1016/j.colsurfa.2020.124627

Xu, Y., Liu, Z., Zhang, X., Wang, Y., Tian, J., Huang, Y., Ma, Y., Zhang, X., & Chen, Y. (2009). A graphene hybrid material covalently functionalized with porphyrin: Synthesis and optical limiting property. *Advanced Materials*, *21*(12), 1275–1279. https://doi.org/10.1002/adma.200801617

Yadav, A., Kumar, A., Sharma, K., & Shukla, M. K. (2019). Investigating the effects of amine functionalized graphene on the mechanical properties of epoxy nanocomposites. *Materials Today: Proceedings*, *11*, 837–842. https://doi.org/10.1016/j.matpr.2019.03.054

Yang, H., Shan, C., Li, F., Zhang, Q., Han, D., & Niu, L. (2009). Convenient preparation of tunably loaded chemically converted graphene oxide/epoxy resin nanocomposites from graphene oxide sheets through two-phase extraction. *Journal of Materials Chemistry*, *19*(46), 8856–8860. https://doi.org/10.1039/b915228h

Yang, L., Phua, S. L., Toh, C. L., Zhang, L., Ling, H., Chang, M., Zhou, D., Dong, Y., & Lu, X. (2013). Polydopamine-coated graphene as multifunctional nanofillers in polyurethane. *RSC Advances*, *3*(18), 6377–6385. https://doi.org/10.1039/c3ra23307c

Yang, S. Y., Lin, W. N., Huang, Y. L., Tien, H. W., Wang, J. Y., Ma, C. C. M., Li, S. M., & Wang, Y. S. (2011a). Synergetic effects of graphene platelets and carbon nanotubes on the mechanical and thermal properties of epoxy composites. *Carbon*, *49*(3), 793–803. https://doi.org/10.1016/j.carbon.2010.10.014

Yang, S. Y., Lin, W. N., Huang, Y. L., Tien, H. W., Wang, J. Y., Ma, C. C. M., Li, S. M., & Wang, Y. S. (2011b). Synergetic effects of graphene platelets and carbon nanotubes on the mechanical and thermal properties of epoxy composites. *Carbon*, *49*(3), 793–803. https://doi.org/10.1016/j.carbon.2010.10.014

Yang, Y., Liu, R., Wu, J., Jiang, X., Cao, P., Hu, X., Pan, T., Qiu, C., Yang, J., Song, Y., Wu, D., & Su, Y. (2015). Bottom-up Fabrication of Graphene on Silicon/Silica Substrate via a Facile Soft-hard Template Approach. *Scientific Reports*, *5*(August), 1–7. https://doi.org/10.1038/srep13480

Yao, H., Hawkins, S. A., & Sue, H. J. (2017). Preparation of epoxy nanocomposites containing well-dispersed graphene nanosheets. *Composites Science and Technology*, *146*, 161–168. https://doi.org/10.1016/j.compscitech.2017.04.026

Yao, H., Li, F., Lutkenhaus, J., Kotaki, M., & Sue, H. J. (2016). High-performance photocatalyst based on nanosized ZnO-reduced graphene oxide hybrid for removal of Rhodamine B under visible light irradiation. *AIMS Materials Science*, *3*(4), 1410–1425. https://doi.org/10.3934/matersci.2016.4.1410

Yavari, F., Fard, H. R., Pashayi, K., Rafiee, M. A., Zamiri, A., Yu, Z., Ozisik, R., Borca-Tasciuc, T., & Koratkar, N. (2011). Enhanced thermal conductivity in a nanostructured phase change composite due to low concentration graphene additives. *Journal of Physical Chemistry C*, *115*(17), 8753–8758. https://doi.org/10.1021/jp200838s

Yazdi, G., Iakimov, T., & Yakimova, R. (2016). Epitaxial Graphene on SiC: A Review of Growth and Characterization. *Crystals*, *6*(5), 53. https://doi.org/10.3390/cryst6050053

You, D., Liang, H., Mai, W., Zeng, R., Tu, M., Zhao, J., & Zha, Z. (2013). Microwave-assisted functionalization of polyurethane surface for improving blood compatibility. *Journal of Industrial and Engineering Chemistry*, *19*(5), 1587–1592. https://doi.org/10.1016/j.jiec.2013.01.027

Yu, D. S., Kuila, T., Kim, N. H., & Lee, J. H. (2014). Enhanced properties of aryl diazonium salt-functionalized graphene/poly(vinyl alcohol) composites. *Chemical Engineering Journal*, *245*, 311–322. https://doi.org/10.1016/j.cej.2014.02.025

Yu, H., Zhang, B., Bulin, C., Li, R., & Xing, R. (2016). High-efficient Synthesis of Graphene Oxide Based on Improved Hummers Method. *Scientific Reports*, *6*(1), 1–7. https://doi.org/10.1038/srep36143

Yu, J., Huang, X., Wu, C., & Jiang, P. (2011). Permittivity, thermal conductivity and thermal stability of poly(vinylidene fluoride)/graphene nanocomposites. *IEEE Transactions on Dielectrics and Electrical Insulation*, *18*(2), 478–484. https://doi.org/10.1109/TDEI.2011.5739452

Yu, T., Zhu, P., Xiong, Y., Chen, H., Kang, S., Luo, H., & Guan, S. (2016). Synthesis of microspherical polyaniline/graphene composites and their application in supercapacitors. *Electrochimica Acta*, *222*, 12–19. https://doi.org/10.1016/j.electacta.2016.11.033

Zaman, I., Kuan, H. C., Meng, Q., Michelmore, A., Kawashima, N., Pitt, T., Zhang, L., Gouda, S., Luong, L., & Ma, J. (2012). A facile approach to chemically modified graphene and its polymer nanocomposites. *Advanced Functional Materials*, *22*(13), 2735–2743. https://doi.org/10.1002/adfm.201103041

Zaman, I., Phan, T. T., Kuan, H. C., Meng, Q., Bao La, L. T., Luong, L., Youssf, O., & Ma, J. (2011). Epoxy/graphene platelets nanocomposites with two levels of interface strength. *Polymer*, *52*(7), 1603–1611. https://doi.org/10.1016/j.polymer.2011.02.003

Zhang, H. Bin, Zheng, W. G., Yan, Q., Jiang, Z. G., & Yu, Z. Z. (2012). The effect of surface chemistry of graphene on rheological and electrical properties of polymethylmethacrylate composites. *Carbon*, *50*(14), 5117–5125. https://doi.org/10.1016/j.carbon.2012.06.052

Zhang, H. Bin, Zheng, W. G., Yan, Q., Yang, Y., Wang, J. W., Lu, Z. H., Ji, G. Y., & Yu, Z. Z. (2010). Electrically conductive polyethylene terephthalate/graphene nanocomposites prepared by melt compounding. *Polymer*, *51*(5), 1191–1196. https://doi.org/10.1016/j.polymer.2010.01.027

Zhang, F., Peng, X., Yan, W., Peng, Z., & Shen, Y. (2011). Nonisothermal crystallization kinetics of in situ nylon 6/graphene composites by differential scanning calorimetry. *Journal of Polymer Science Part B: Polymer Physics*, *49*(19), 1381–1388. https://doi.org/10.1002/polb.22321

Zhang, Y., Wang, Y., Yu, J., Chen, L., Zhu, J., & Hu, Z. (2014a). Tuning the interface of graphene platelets/epoxy composites by the covalent grafting of polybenzimidazole. *Polymer*, *55*(19), 4990–5000. https://doi.org/10.1016/j.polymer.2014.07.045

Zhang, Y., Wang, Y., Yu, J., Chen, L., Zhu, J., & Hu, Z. (2014b). Tuning the interface of graphene platelets/epoxy composites by the covalent grafting of polybenzimidazole. *Polymer*, *55*(19), 4990–5000. https://doi.org/10.1016/j.polymer.2014.07.045