EFFECT OF GRAPHENE NANOREINFORCEMENT ON MOISTURE ABSORPTION AND MECHANICAL PROPERTIES OF EPOXY ADHESIVE JOINT

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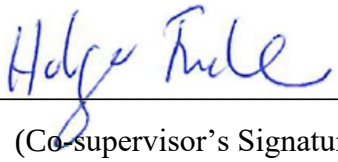

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti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

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ABSTRAK

Perekat boleh digunakan untuk menyambung pelbagai jenis substrat dan digunakan dalam pelbagai industri. Walau bagaimanapun, terdapat masalah dengan pendedahan kepada kelembapan. Sesetengah perekat cenderung menyerap lembapan dalam persekitaran lembap, yang membawa kepada penurunan kekuatan cantuman. Penambahan nanopartikel ke dalam perekat polimer dijangka mengurangkan pengambilan air dengan meningkatkan rintangan air terhadap serangan lembapan, seterusnya, mengekalkan kekuatan cantuman, dan ia telah dikaji berkali-kali pada masa lalu. Walau bagaimanapun, kajian menunjukkan trend yang agak tidak konsisten dalam tingkah laku penyerapan air, dan ada yang bercanggah dengan pendekatan teori bahawa penyerapan air menyebabkan peningkatan kekuatan cantuman. Dalam kerja semasa, kesan penambahan Graphene Nanoplatelets (GNP) ke atas tingkah laku penyerapan air, sifat mekanikal spesimen ASTM E8 dan perekat tertindih tunggal (PTT) dengan menggunakan perekat epoksi telah disiasat. Perekat epoksi dengan pelbagai jumlah GNP (0.0, 0.5, 1.0, 1.5, dan 2.0 wt%) telah digunakan untuk melekat aluminium yang dikenakan dengan pelbagai tempoh rendaman (0, 10, 20, 30, 40, 50, dan 60 hari). Kemudian, kesan penambahan GNP terhadap penyerapan air, kadar resapan air, sifat tegangan dan ricih, dan pemanjangan patah serta mod patah spesimen telah disiasat. Berbanding dengan perekat tulen, spesimen lembapan pada kandungan GNP yang rendah (iaitu 1.0 wt%), telah menghasilkan peningkatan bagi penyerapan air dan kadar penyerapan air sehingga 99.77% pada peringkat rendaman awal, manakala, mengakibatkan penurunan sehingga ke 18.37% pada tempoh rendaman yang lebih lama. Pada kandungan GNP yang tinggi (iaitu 2.0 wt%), kadar penyerapan air dan penyerapan air yang lebih tinggi sehingga 124.63% telah direkodkan pada tempoh rendaman yang lebih rendah (iaitu 10-20 hari), manakala penyerapan air dan kadar penyerapan air yang rendah sehingga 51.50% diperhatikan pada tempoh rendaman yang lebih tinggi (iaitu 30-60 hari). Sifat tegangan spesimen ASTM E8 telah menunjukkan peningkatan dalam kemuluran spesimen sehingga 933.43% pada 1.0 wt% jika dibandingkan dengan perekat tulen. Pada masa yang sama, pengurangan tegasan tegangan sehingga 74.35% diperhatikan pada 1.5 wt%. Pekali korelasi R menunjukkan peningkatan dalam kemuluran spesimen ASTM E8 apabila penyerapan air meningkat pada semua kandungan GNP, dengan nilai R yang lebih tinggi diperhatikan pada 1.0 dan 1.5 wt%. Pada masa yang sama, tegasan tegangan berkurang dengan peningkatan penyerapan air pada semua kandungan GNP, dengan nilai R terendah diperhatikan pada 1.0 wt%. Mikroskop Elektron Pengimbasan Pelepasan Medan mendedahkan bahawa terdapat beberapa mekanisma peneguhan yang terlibat serta penggumpalan GNP yang mempengaruhi tingkah laku kegagalan spesimen. Sifat ricih PTT secara amnya menunjukkan penurunan tegasan ricih sehingga 64.84% pada 2.0 wt% dan penurunan kemuluran sehingga 45.98% pada 1.5 wt% apabila tempoh rendaman ditingkatkan. Penambahan GNP ke dalam matriks epoksi telah mengakibatkan percampuran kawasan rekahan. Peningkatan kawasan rekahan menjeleket (RM) sepadan dengan prestasi rendah tegasan ricih (atau tegasan menjeleket) dan pemanjangan patah yang rendah pada GNP/epoksi, manakala, pertambahan kawasan rekahan rekatan (RR) sepadan dengan prestasi tinggi tegasan ricih (atau tegasan menjeleket) dan pemanjangan patah yang lebih tinggi. Secara ringkasnya, penambahan GNP ke dalam perekat epoksi meningkatkan penyerapan air dan kadar penyerapan air pada tempoh rendaman awal, manakala, mengurangkannya pada tempoh rendaman yang lebih lama. Sementara itu, penambahan GNP meningkatkan kemuluran spesimen ASTM E8, tetapi melemahkan sifat matriks perekat, menyebabkan kegagalan PTT berlaku pada daya yang lebih rendah dan kemuluran yang lebih rendah. Spesimen ini mempamerkan tingkah laku percampuran kawasan rekahan. Peningkatan kawasan RM sepadan dengan prestasi rendah tegasan menjeleket. Berdasarkan spesimen ASTM E8, didapati bahawa kekuatan tegangan, yang paling kurang bergantung dengan penyerapan air, dikaitkan dengan pemanjangan patah terbesar adalah pada kandungan GNP 1.0 wt%.

ABSTRACT

Adhesive can be used to join various types of substrates and is used in various industries. However, there is a problem with exposure to moisture/humidity. Some adhesives tend to absorb moisture in humid environments, leading to a decrease in joint strength. Addition of nanoparticles into polymer adhesive is expected to reduce water uptake by increasing the water resistance against moisture attack, subsequently, maintain the joint strength, and it has been studied numerous times previously. However, some studies showed an opposing manner to the improvement. Therefore, in the current work, the effects of Graphene Nanoplatelets (GNP) reinforcement on the moisture absorption behaviour, mechanical properties of ASTM E8 specimens and single lap joints with epoxy adhesive were investigated. Epoxy adhesive with different GNP contents (0.0, 0.5, 1.0, 1.5, and 2.0 wt%) was used to join aluminium adherends that were subjected to different immersion periods (0, 10, 20, 30, 40, 50, and 60 days). Then, the effect of GNP reinforcement on water uptake, water absorption rate, tensile and shear properties, and fracture mode of the joint specimens was investigated. As compared to the pristine adhesive, moisture specimens at lower GNP content (i.e.,0.5 and 1.0 wt%), the reinforcement resulted in an increase of water uptake and water absorption rate up to 99.77% at early immersion stage, while, resulted in a decrease up to 18.37% for longer immersion period. At higher GNP content (i.e., 1.5 and 2.0 wt%), higher water uptake and water absorption rate up to 124.63% were recorded at lower immersion periods (i.e., 10-20 days), whereas lower water uptake and water absorption rate up to 51.50% were observed at higher immersion period (i.e., 30-60 days). The tensile properties of the ASTM E8 specimens demonstrated an enhancement in the ductility of the specimens by up to 933.43% for 1.0 wt% when compared to pristine adhesive. At the same time, reduction in tensile stress up to 74.35% was observed for 1.5 wt%. The correlation coefficient R showed an improvement in ductility of ASTM E8 specimens as water uptake increased for all GNP contents, with a higher R value observed for 1.0 and 1.5 wt%. Simultaneously, tensile stress decreased with increasing water uptake for all GNP contents, with the lowest R value observed at 1.0 wt%. The Field Emission Scanning Electron Microscope revealed that there were some possible toughening mechanisms and some GNP agglomerations which affect the failure behaviour of the specimens. The shear properties of single lap joints generally showed a decrease in shear stress performance up to 64.84% at 2.0 wt% when the immersion period was increased. Fracture elongation demonstrated reduction in ductility up to 45.98% at 1.5 wt%. Incorporation of GNP into the epoxy matrix resulted in a mixed mode fracture behaviour. The increment of cohesive fracture (CF) corresponded to the lower shear stress performance (or cohesive strength) and the lower fracture elongation of the specimens, while the increment of adhesive fracture (AF) corresponded to the higher shear stress performance (or cohesive strength) and the higher fracture elongation of the specimens. In brief, the addition of GNP into epoxy adhesive increased the water uptake and water absorption rate at early immersion period, while, reducing them at a longer immersion period. Meanwhile, the GNP addition improved the ductility of the ASTM E8 specimens, but weakened the properties of the adhesive matrix, causing failure of the single lap joints occurred at lower forces and lower ductility. These specimens exhibited mixed mode fracture behavior. Higher CF region corresponded to lower cohesive strength. Based on the ASTM E8 specimens, it was found that the tensile strength, which corresponded least with water uptake, associated with the largest fracture elongation is at 1.0 wt% GNP content.

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Abbasi, Z., Jazani, O. M., & Sohrabian, M. (2021). Designing of high-performance epoxy adhesive with recycled polymers and silica nano particles (SNPs) in epoxy/carbon fiber composite-steel bonded joints: Mechanical properties, thermal stability and toughening mechanisms. *Journal of the Taiwan Institute of Chemical Engineers*, *123*, 310–327. https://doi.org/10.1016/j.jtice.2021.05.016

Abdelmola, F., & Carlsson, L. A. (2020). *State of water in void-free and void-containing epoxy specimens*. *April*. https://doi.org/10.1177/0731684419833469

Abenojar, J., Pantoja, M., Martínez, M. A., & Del Real, J. C. (2015). Aging by moisture and/or temperature of epoxy/SiC composites: Thermal and mechanical properties. *Journal of Composite Materials*, *49*(24), 2963–2975. https://doi.org/10.1177/0021998314558496

Abramoff, M. D., Magalhães, P. J., & Ram, S. J. (2004). Image Processing with ImageJ. In *Biophotonics International* (Vol. 11, Issue 7).

Ahmadi, Z. (2019). Nanostructured epoxy adhesives: A review. *Progress in Organic Coatings*, *135*(March), 449–453. https://doi.org/10.1016/j.porgcoat.2019.06.028

Akpinar, I. A., Gürses, A., Akpinar, S., Gültekin, K., Akbulut, H., & Ozel, A. (2018). Investigation of mechanical and thermal properties of nanostructure-doped bulk nanocomposite adhesives. *The Journal of Adhesion*, *94*(11), 847–866. https://doi.org/10.1080/00218464.2017.1415809

Alies, M. S. I., & Khalil, N. Z. (2022). Effect of alumina/graphene hybrid nano reinforcement to the adhesion and mechanical properties of adhesively bonded aluminum alloy with epoxy. *Materials Today: Proceedings*, *51*, 1437–1443. https://doi.org/10.1016/j.matpr.2021.12.087

Alves, D. L., Campilho, R. D. S. G., Moreira, R. D. F., Silva, F. J. G., & Cardoso, M. G. (2019). Effect of material hybridization on the strength of scarf adhesive joints. *Procedia Manufacturing*, *38*, 1244–1251. https://doi.org/https://doi.org/10.1016/j.promfg.2020.01.216

Alves, D. L., Campilho, R. D. S. G., Moreira, R. D. F., Silva, F. J. G., & da Silva, L. F. M. (2018). Experimental and numerical analysis of hybrid adhesively-bonded scarf joints. *International Journal of Adhesion and Adhesives*, *83*, 87–95. https://doi.org/10.1016/j.ijadhadh.2018.05.011

Aradhana, R., Mohanty, S., & Nayak, S. K. (2018). High performance epoxy nanocomposite adhesive: Effect of nanofillers on adhesive strength, curing and degradation kinetics. *International Journal of Adhesion and Adhesives*, *84*(March), 238–249. https://doi.org/10.1016/j.ijadhadh.2018.03.013

Aslan, A., Salur, E., Düzcükoğlu, H., Sinan Şahin, Ö., & Ekrem, M. (2021). The effects of harsh aging environments on the properties of neat and MWCNT reinforced epoxy resins. *Construction and Building Materials*, *272*, 121929. https://doi.org/10.1016/j.conbuildmat.2020.121929

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. In *European Journal of Operational Research* (Vol. 253, Issue 1, pp. 1–13). Elsevier B.V. https://doi.org/10.1016/j.ejor.2015.12.023

Bal, S., & Saha, S. (2017). Mechanical performances of hygrothermally conditioned CNT/epoxy composites using seawater. *Journal of Polymer Engineering*, *37*(6), 633–645. https://doi.org/10.1515/polyeng-2016-0121

Barbosa, N. G. C. C., Campilho, R. D. S. G. S. G., Silva, F. J. G. G., & Moreira, R. D. F. F. (2018). Comparison of different adhesively-bonded joint types for mechanical structures. *Applied Adhesion Science*, *6*(1), 15. https://doi.org/10.1186/s40563-018-0116-1

Barrera, C. S., & Cornish, K. (2017). Processing and mechanical properties of natural rubber/waste-derived nano filler composites compared to macro and micro filler composites. *Industrial Crops and Products*, *107*(May), 217–231. https://doi.org/10.1016/j.indcrop.2017.05.045

Bhattacharya, M. (2016). Polymer Nanocomposites-A Comparison between Carbon Nanotubes, Graphene, and Clay as Nanofillers. *Materials*, *9*(262). https://doi.org/10.3390/ma9040262

Bresson, G., Jumel, J., Shanahan, M. E. R., & Serin, P. (2012). Strength of adhesively bonded joints under mixed axial and shear loading. *International Journal of Adhesion and Adhesives*, *35*, 27–35. https://doi.org/10.1016/j.ijadhadh.2011.12.006

Capiel, G., Uicich, J., Alvarez, V., & Montemartini, P. (2017). Improving the water resistance of epoxy–anhydride matrices by the incorporation of bentonite. *Polymers for Advanced Technologies*, *28*(7), 886–896. https://doi.org/10.1002/pat.3993

Carbas, R. J. C., da Silva, L. F. M., & Andrés, L. F. S. (2017). Functionally graded adhesive joints by graded mixing of nanoparticles. *International Journal of Adhesion and Adhesives*, *76*(July), 30–37. https://doi.org/10.1016/j.ijadhadh.2017.02.004

Cataldi, P., Athanassiou, A., & Bayer, I. S. (2018). Graphene nanoplatelets-based advanced materials and recent progress in sustainable applications. *Applied Sciences (Switzerland)*, *8*(9), 1438. https://doi.org/10.3390/app8091438

Cavezza, F., Boehm, M., Terryn, H., & Hauffman, T. (2020). A review on adhesively bonded aluminium joints in the automotive industry. *Metals*, *10*(6), 1–32. https://doi.org/10.3390/met10060730

Cerqueira, J. C., Penha, J. da S., Oliveira, R. S., Guarieiro, L. L. N., Melo, P. da S., Viana, J. D., & Machado, B. A. S. (2017). Production of biodegradable starch nanocomposites using cellulose nanocrystals extracted from coconut fibers. *Polímeros*, *27*(4), 320–329. https://doi.org/10.1590/0104-1428.05316

Chan, J. X., Wong, J. F., Petrů, M., Hassan, A., Nirmal, U., Othman, N., & Ilyas, R. A. (2021). Effect of nanofillers on tribological properties of polymer nanocomposites: A review on recent development. In *Polymers* (Vol. 13, Issue 17, p. 2867). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/polym13172867

Chan, M. L., Lau, K. T., Wong, T. T., & Cardona, F. (2011). Interfacial bonding characteristic of nanoclay/polymer composites. *Applied Surface Science*, *258*(2), 860–864. https://doi.org/10.1016/j.apsusc.2011.09.016

Chazot, C. A. C., & Hart, A. J. (2019). Understanding and control of interactions between carbon nanotubes and polymers for manufacturing of high-performance composite materials. *Composites Science and Technology*, *183*(June), 107795. https://doi.org/10.1016/j.compscitech.2019.107795

Choudalakis, G., & Gotsis, A. D. (2009). Permeability of polymer/clay nanocomposites: A review. *European Polymer Journal*, *45*(4), 967–984. https://doi.org/10.1016/j.eurpolymj.2009.01.027

Ciprai, D., Jacob, K., & Tannenbaum, R. (2006). Characterization of polymer nanocomposite interphase and its impact on mechanical properties. *Macromolecules*, *39*(19), 6565–6573. https://doi.org/10.1021/ma0602270

Costa, M., Viana, G., da Silva, L. F. M., Campilho, R. D. S. G., Silva, L. F. M., & Campilho, R. D. S. G. (2017). Effect of humidity on the fatigue behaviour of adhesively bonded aluminium joints. *Latin American Journal of Solids and Structures*, *14*(1), 174–187. https://doi.org/10.1590/1679-78252976

Cruz, C., Mosquera-Artamonov, J., Santillán, S., & Gámez-Cuatzin, H. (2018). Influence of the roughness method, joint configuration and adhesive thickness on the cut resistance of ferritic stainless steel surfaces joined by methyl methacrylate. *Revista de Metalurgia*, *54*, 120. https://doi.org/10.3989/revmetalm.120

D'Orazio, L., & Grippo, A. (2016). A water-dispersed titanium dioxide/poly(carbonate urethane) nanocomposite for protecting cultural heritage: Eco-sustainable treatments on Neapolitan Yellow Tuff. *Progress in Organic Coatings*, *99*, 412–419. https://doi.org/10.1016/j.porgcoat.2016.06.018

Delzendehrooy, F., Akhavan-Safar, A., Barbosa, A. Q., Beygi, R., Cardoso, D., Carbas, R. J. C., Marques, E. A. S., & da Silva, L. F. M. (2022). A comprehensive review on structural joining techniques in the marine industry. *Composite Structures*, *289*(February), 115490. https://doi.org/10.1016/j.compstruct.2022.115490

Deng, S., Zhang, J., Ye, L., & Wu, J. (2008). Toughening epoxies with halloysite nanotubes. *Polymer*, *49*(23), 5119–5127. https://doi.org/10.1016/j.polymer.2008.09.027

Dillingham, R. G., & Oakley, B. R. (2006). Surface Energy and Adhesion in Composite–Composite Adhesive Bonds. *The Journal of Adhesion*, *82*(4), 407–426. https://doi.org/10.1080/00218460600683944

Domun, N., Hadavinia, H., Zhang, T., Sainsbury, T., Liaghat, G. H., & Vahid, S. (2015). Improving the fracture toughness and the strength of epoxy using nanomaterials – a review of the current status. *Nanoscale*, *7*, 10294–10329. https://doi.org/10.1039/c5nr01354b

Dorigato, A., & Pegoretti, A. (2011). The role of alumina nanoparticles in epoxy adhesives. *Journal of Nanoparticle Research*. https://doi.org/10.1007/s11051-010-0130-0

Dorigato, A., & Pegoretti, A. (2012). Development and thermo-mechanical behavior of nanocomposite epoxy adhesives. *Polymers for Advanced Technologies*, *23*(3), 660–668. https://doi.org/10.1002/pat.1942

Eayal Awwad, K. Y., Yousif, B. F., Fallahnezhad, K., Saleh, K., & Zeng, X. (2021). Influence of graphene nanoplatelets on mechanical properties and adhesive wear performance of epoxy-based composites. *Friction*, *9*(4), 856–875. https://doi.org/10.1007/s40544-020-0453-5

Ebnesajjad, S. (2011). Introduction and adhesion theories. In *Handbook of Adhesives and Surface Preparation* (pp. 3–13). Elsevier Inc. https://doi.org/10.1016/B978-1-4377-4461-3.10001-X

Ebnesajjad, S., & Landrock, A. H. (2015). Durability of Adhesive Bonds. In S. Ebnesajjad & A. H. Landrock (Eds.), *Adhesives Technology Handbook (Third Edition)* (pp. 297–338). William Andrew Publishing. https://doi.org/10.1016/B978-0-323-35595-7.00011-5

Eda, G., & Chhowalla, M. (2009). *Graphene-based Composite Thin Films for Electronics*. 0–4. https://doi.org/10.1021/nl8035367

Encyclopedia, N. W. (2019). *Adhesive*. https://www.newworldencyclopedia.org/entry/Adhesive

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

Fernández-García, M., & Chiang, M. Y. M. M. (2002). Effect of hygrothermal aging history on sorption process, swelling, and glass transition temperature in a particle-filled epoxy-based adhesive. *Journal of Applied Polymer Science*, *84*(8), 1581–1591. https://doi.org/10.1002/app.10447

Firdosh, S., Narasimha Murthy, H. N., Angadi, G., & Raghavendra, N. (2018). Investigation of water absorption characteristics of nano-gelcoat for marine application. *Progress in Organic Coatings*, *114*(October 2017), 173–187. https://doi.org/10.1016/j.porgcoat.2017.10.004

Fu, J., Zhang, M., Jin, L., Liu, L., Li, N., Shang, L., Li, M., Xiao, L., & Ao, Y. (2019). Enhancing interfacial properties of carbon fibers reinforced epoxy composites via Layer-by-Layer self assembly GO/SiO 2 multilayers films on carbon fibers surface. *Applied Surface Science*, *470*(August 2018), 543–554. https://doi.org/10.1016/j.apsusc.2018.11.168

Geng, Y., Liu, M. Y., Li, J., Shi, X. M., & Kim, J. K. (2008). Effects of surfactant treatment on mechanical and electrical properties of CNT/epoxy nanocomposites. *Composites Part A: Applied Science and Manufacturing*, *39*(12), 1876–1883. https://doi.org/10.1016/j.compositesa.2008.09.009

Glaskova-Kuzmina, T., Aniskevich, A., Papanicolaou, G., Portan, D., Zotti, A., Borriello, A., & Zarrelli, M. (2020). Hydrothermal aging of an epoxy resin filled with carbon nanofillers. *Polymers*, *12*(5). https://doi.org/10.3390/POLYM12051153

Glaskova, T., Aniskevich, A., Martone, A., Giordano, M., & Zarrelli, M. (2016). Effect of moisture on elastic and viscoelastic properties of epoxy and epoxy-based carbon fibre reinforced plastic filled with multiwall carbon nanotubes. *Composites Part A: Applied Science and Manufacturing*, *90*, 522–527. https://doi.org/10.1016/j.compositesa.2016.08.026

Grefe, H., Kandula, M. W., & Dilger, K. (2020). Influence of the fibre orientation on the lap shear strength and fracture behaviour of adhesively bonded composite metal joints at high strain rates. *International Journal of Adhesion and Adhesives*, *97*, 102486. https://doi.org/10.1016/j.ijadhadh.2019.102486

Gude, M. R., Prolongo, S. G., & Ureña, A. (2013). Hygrothermal ageing of adhesive joints with nanoreinforced adhesives and different surface treatments of carbon fibre/epoxy substrates. *International Journal of Adhesion and Adhesives*, *40*, 179–187. https://doi.org/10.1016/j.ijadhadh.2012.09.005

Guo, Q., Zhu, P., Li, G., Wen, J., Wang, T., Lu, D. (Daniel), Sun, R., & Wong, C. (2017). Study on the effects of interfacial interaction on the rheological and thermal performance of silica nanoparticles reinforced epoxy nanocomposites. *Composites Part B: Engineering*, *116*, 388–397. https://doi.org/10.1016/j.compositesb.2016.10.081

Gupta, S. K., Shukla, D. K., & Kaustubh Ravindra, D. (2021). Effect of nanoalumina in epoxy adhesive on lap shear strength and fracture toughness of aluminium joints. *Journal of Adhesion*, *97*(2), 117–139. https://doi.org/10.1080/00218464.2019.1641088

Hanemann, T., & Szabó, D. V. (2010). Polymer-nanoparticle composites: From synthesis to modern applications. In *Materials* (Vol. 3, Issue 6). https://doi.org/10.3390/ma3063468

Hanumantharaya, R., Sogalad, I., & Basavarajappa, S. (2020). Investigations on the

influence of nano reinforcement on strength of adhesively bonded joints. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.10.097

Hartwig, A., Luhring, A., & Trautmann, J. (2009). Spheroidal nanoparticles in epoxide-based adhesives. *Macromolecular Materials and Engineering*, *294*(6–7), 363–379. https://doi.org/10.1002/mame.200900031

Hussain, Q., Ruangrassamee, A., Tangtermsirikul, S., & Joyklad, P. (2020). Behavior of concrete confined with epoxy bonded fiber ropes under axial load. *Construction and Building Materials*, *263*, 120093. https://doi.org/10.1016/j.conbuildmat.2020.120093

Idolor, O., Guha, R. D., Berkowitz, K., Geiger, C., Davenport, M., & Grace, L. (2021). Polymer-water interactions and damage detection in polymer matrix composites. *Composites Part B: Engineering*, *211*(December 2020), 108637. https://doi.org/10.1016/j.compositesb.2021.108637

Iqbal, A. K. M. P. A., Sakib, N., Iqbal, A. K. M. P. A., & Nuruzzaman, D. M. (2020). Graphene-based nanocomposites and their fabrication, mechanical properties and applications. *Materialia*, *12*(June), 100815. https://doi.org/10.1016/j.mtla.2020.100815

Jojibabu, P., Jagannatham, M., Haridoss, P., Janaki Ram, G. D., Deshpande, A. P., & Bakshi, S. R. (2016). Effect of different carbon nano-fillers on rheological properties and lap shear strength of epoxy adhesive joints. *Composites Part A: Applied Science and Manufacturing*, *82*, 53–64. https://doi.org/10.1016/j.compositesa.2015.12.003

Jojibabu, P., Ram, G. D. J. J., Deshpande, A. P., Bakshi, S. R., Panta, J., Ram, G. D. J. J., Deshpande, A. P., Bakshi, S. R., Jojibabu, P., Ram, G. D. J. J., Deshpande, A. P., & Bakshi, S. R. (2017). Effect of carbon nano-filler addition on the degradation of epoxy adhesive joints subjected to hygrothermal aging. *Polymer Degradation and Stability*, *140*, 84–94. https://doi.org/10.1016/j.polymdegradstab.2017.04.017

Jojibabu, P., Zhang, Y. X., & Prusty, B. G. (2020). A review of research advances in epoxy-based nanocomposites as adhesive materials. *International Journal of Adhesion and Adhesives*, *96*(February 2019), 102454. https://doi.org/10.1016/j.ijadhadh.2019.102454

Jouyandeh, M., Moini Jazani, O., Navarchian, A. H., & Saeb, M. R. (2016). High-performance epoxy-based adhesives reinforced with alumina and silica for carbon fiber composite/steel bonded joints. *Journal of Reinforced Plastics and*

Composites, *35*(23), 1685–1695. https://doi.org/10.1177/0731684416665248

Kanda, M., Puggal, S., Dhall, N., & Sharma, A. (2018). Recent Developments in the Fabrication, Characterization, and Properties Enhancement of Polymer Nanocomposites: A Critical Review. *Materials Today: Proceedings*, *5*(14), 28243–28252. https://doi.org/10.1016/j.matpr.2018.10.069

Karthikeyan, L., Robert, T. M., Mathew, D., Desakumaran Suma, D., & Thomas, D. (2021). Novel epoxy resin adhesives toughened by functionalized poly (ether ether ketone) s. *International Journal of Adhesion and Adhesives*, *106*(February), 102816. https://doi.org/10.1016/j.ijadhadh.2021.102816

Katsiropoulos, C. V., Chamos, A. N., Tserpes, K. I., & Pantelakis, S. G. (2012). Fracture toughness and shear behavior of composite bonded joints based on a novel aerospace adhesive. *Composites Part B: Engineering*, *43*(2), 240–248. https://doi.org/10.1016/j.compositesb.2011.07.010

Kerur, S., & S, S. (2019). Investigation of Environmental Degradation on Joint Properties of Polymer Adhesive Joints in Salt Water Environment. *International Journal of Engineering Sciences*, *11*(4). https://doi.org/10.36224/ijes.110403

Kesavulu, A., & Mohanty, A. (2020). Tribological characterization of graphene nanoplatelets/alumina particles filled epoxy hybrid nanocomposites. *Journal of Applied Polymer Science*, *137*(46), 1–12. https://doi.org/10.1002/app.49518

Keshavarz, R., Aghamohammadi, H., & Eslami-Farsani, R. (2020). The effect of graphene nanoplatelets on the flexural properties of fiber metal laminates under marine environmental conditions. *International Journal of Adhesion and Adhesives*, *103*(August), 102709. https://doi.org/10.1016/j.ijadhadh.2020.102709

Khademian, M., & Eisazadeh, H. (2015). Preparation and characterization emulsion of PANI-TiO2 nanocomposite and its application as anticorrosive coating. *Journal of Polymer Engineering*, *35*(6), 597–603. https://doi.org/10.1515/polyeng-2014-0272

Khalil, N. Z., Johanne, M. F., & Ishak, M. (2019). Influence of Al2O3 nanoreinforcement on the adhesion and thermomechanical properties for epoxy adhesive. *Composites Part B: Engineering*, *172*(September 2018), 9–15. https://doi.org/10.1016/j.compositesb.2019.05.007

Khalil, N. Z., Vajpai, S. K., Ota, M., & Ameyama, K. (2016). Application of Al-Si semi-solid reaction for fabricating harmonic structured Al based alloy. *Materials*

Transactions, *57*(9), 1433–1439. https://doi.org/10.2320/matertrans.MH201516

Khashaba, U. A., Aljinaidi, A. A., & Hamed, M. A. (2014). Nanofillers modification of Epocast 50-A1/946 epoxy for bonded joints. *Chinese Journal of Aeronautics*, *27*(5), 1288–1300. https://doi.org/10.1016/j.cja.2014.08.007

Khoramishad, H., & Alizadeh, O. (2018). Effects of silicon carbide nanoparticles and multi-walled carbon nanotubes on water uptake and resultant mechanical properties degradation of polymer nanocomposites immersed in hot water. *Polymer Composites*, *39*(S2), E883–E890. https://doi.org/10.1002/pc.24303

Khoramishad, H., Alizadeh, O., & da Silva, L. F. M. M. (2018). Effect of multi-walled carbon nanotubes and silicon carbide nanoparticles on the deleterious influence of water absorption in adhesively bonded joints. *Journal of Adhesion Science and Technology*, *32*(16), 1795–1808. https://doi.org/10.1080/01694243.2018.1447295

Khoramishad, H., & Khakzad, M. (2018). Toughening epoxy adhesives with multi-walled carbon nanotubes. *The Journal of Adhesion*, *94*(1), 15–29. https://doi.org/10.1080/00218464.2016.1224184

Kim, D. H., & Kim, H. S. (2013). Waterproof characteristics of nanoclay/epoxy nanocomposite in adhesively bonded joints. *Composites Part B: Engineering*, *55*, 86–95. https://doi.org/10.1016/j.compositesb.2013.05.041

Kirch, W. (Ed.). (2008). Pearson's Correlation Coefficient. In *Encyclopedia of Public Health* (pp. 1090–1091). Springer Netherlands. https://doi.org/10.1007/978-1-4020-5614-7_2569

Koch, F., & Lutz, A. (2018). High modulus structural body shop adhesives. *Adhesion Adhesives and Sealants*, *15*(2), 17–19. https://doi.org/10.1007/s35784-018-0008-6

Kong, N., Khalil, N. Z., & Fricke, H. (2021). Moisture Absorption Behavior and Adhesion Properties of GNP/Epoxy Nanocomposite Adhesives. *Polymers*, *13*(11), 1850. https://doi.org/10.3390/polym13111850

Konstantakopoulou, M., & Kotsikos, G. (2016). Effect of MWCNT filled epoxy adhesives on the quality of adhesively bonded joints. *Plastics, Rubber and Composites*, *45*(4), 166–172. https://doi.org/10.1080/14658011.2016.1165788

Kumar, A., Ghosh, P. K., Yadav, K. L., & Kumar, K. (2017). Thermo-mechanical and

anti-corrosive properties of MWCNT/epoxy nanocomposite fabricated by innovative dispersion technique. *Composites Part B*. https://doi.org/10.1016/j.compositesb.2017.01.046

Kumar, A., Kumar, K., Ghosh, P. K., Rathi, A., Yadav, K. L., & Raman. (2018). MWCNTs toward superior strength of epoxy adhesive joint on mild steel adherent. *Composites Part B: Engineering*, *143*, 207–216. https://doi.org/10.1016/j.compositesb.2018.01.016

Kwon, D. J., Shin, P. S., Kim, J. H., Baek, Y. M., Park, H. S., DeVries, K. L., & Park, J. M. (2017). Interfacial properties and thermal aging of glass fiber/epoxy composites reinforced with SiC and SiO2 nanoparticles. *Composites Part B: Engineering*, *130*, 46–53. https://doi.org/10.1016/j.compositesb.2017.07.045

Ladhari, A., Ben Daly, H., Belhadjsalah, H., Cole, K. C., & Denault, J. (2010). Investigation of water absorption in clay-reinforced polypropylene nanocomposites. *Polymer Degradation and Stability*, *95*(4), 429–439. https://doi.org/10.1016/j.polymdegradstab.2009.12.001

Lakshmi, M. S., Narmadha, B., & Reddy, B. S. R. (2008). Enhanced thermal stability and structural characteristics of different MMT-Clay/epoxy-nanocomposite materials. *Polymer Degradation and Stability*, *93*(1), 201–213. https://doi.org/10.1016/j.polymdegradstab.2007.10.005

Lee, D. H., & Cho, N. G. (2012). Assessment of surface profile data acquired by a stylus profilometer. *Measurement Science and Technology*, *23*(10). https://doi.org/10.1088/0957-0233/23/10/105601

Leger, R., Roy, A., & Grandidier, J. C. (2010). Non-classical water diffusion in an industrial adhesive. *International Journal of Adhesion and Adhesives*, *30*(8), 744–753. https://doi.org/10.1016/j.ijadhadh.2010.07.008

Licari, J. J., & Swanson, D. W. (2011). Chemistry, Formulation, and Properties of Adhesives. In J. J. Licari & D. W. Swanson (Eds.), *Adhesives Technology for Electronic Applications (Second Edition)* (pp. 75–141). William Andrew Publishing. https://doi.org/10.1016/B978-1-4377-7889-2.10003-8

Lin, Y. C., & Chen, X. (2005). Moisture sorption–desorption–resorption characteristics and its effect on the mechanical behavior of the epoxy system. *Polymer*, *46*(25), 11994–12003. https://doi.org/10.1016/j.polymer.2005.10.002

Lin, Y. C., Chen, X., Zhang, H. J., & Wang, Z. P. (2006). Effects of hygrothermal aging on epoxy-based anisotropic conductive film. *Materials Letters*, *60*(24), 2958–2963. https://doi.org/10.1016/j.matlet.2006.02.024

Liu, S., Chevali, V. S., Xu, Z., Hui, D., & Wang, H. (2018). A review of extending performance of epoxy resins using carbon nanomaterials. In *Composites Part B: Engineering* (Vol. 136, pp. 197–214). Elsevier Ltd. https://doi.org/10.1016/j.compositesb.2017.08.020

Liu, S., Yan, H., Fang, Z., & Wang, H. (2014). Effect of graphene nanosheets on morphology , thermal stability and flame retardancy of epoxy resin. *COMPOSITES SCIENCE AND TECHNOLOGY*, *90*, 40–47. https://doi.org/10.1016/j.compscitech.2013.10.012

Liu, W., Hoa, S. V., & Pugh, M. (2005). Fracture toughness and water uptake of high-performance epoxy/nanoclay nanocomposites. *Composites Science and Technology*, *65*(15-16 SPEC. ISS.), 2364–2373. https://doi.org/10.1016/j.compscitech.2005.06.007

Liu, W., Hoa, S. V., & Pugh, M. (2008). Water uptake of epoxy-clay nanocomposites: Experiments and model validation. *Composites Science and Technology*, *68*(9), 2066–2072. https://doi.org/10.1016/j.compscitech.2007.07.024

Loh, W. K., Crocombe, A. D., Abdel Wahab, M. M., Ashcroft, I. A., Wahab, M. M. A., & Ashcroft, I. A. (2005). Modelling anomalous moisture uptake, swelling and thermal characteristics of a rubber toughened epoxy adhesive. *International Journal of Adhesion and Adhesives*, *25*(1), 1–12. https://doi.org/10.1016/j.ijadhadh.2004.02.002

López, C. C., Lefebvre, X., Brusselle-Dupend, N., Klopffer, M. H., Cangémi, L., Castagnet, S., & Grandidier, J. C. (2016). Effect of porosity and hydrostatic pressure on water absorption in a semicrystalline fluoropolymer. *Journal of Materials Science*, *51*(8), 3750–3761. https://doi.org/10.1007/s10853-015-9692-7

Mactabi, R., Rosca, I. D., & Hoa, S. V. (2013). Monitoring the integrity of adhesive joints during fatigue loading using carbon nanotubes. *Composites Science and Technology*, *78*, 1–9. https://doi.org/10.1016/j.compscitech.2013.01.020

Mariam, M., Afendi, M., Abdul Majid, M. S., Ridzuan, M. J. M., Azmi, A. I., & Sultan, M. T. H. (2019). Influence of hydrothermal ageing on the mechanical properties of an adhesively bonded joint with different adherends. *Composites Part B: Engineering*, *165*, 572–585. https://doi.org/10.1016/j.compositesb.2019.02.032

Marques, A. C., Mocanu, A., Tomic, N. Z., Balos, S., Stammen, E., Lundevall, A., Abrahami, S. T., Günther, R., Kok, J. M. M. De, & Freitas, S. T. De. (2020). *Review on Adhesives and Surface Treatments for Structural Applications : Recent Developments on Sustainability and Implementation for Metal and Composite Substrates*. https://doi.org/10.3390/ma13245590

Martínez-Landeros, V. H., Vargas-Islas, S. Y., Cruz-González, C. E., Barrera, S., Mourtazov, K., & Ramírez-Bon, R. (2019). Studies on the influence of surface treatment type, in the effectiveness of structural adhesive bonding, for carbon fiber reinforced composites. *Journal of Manufacturing Processes*, *39*(January), 160–166. https://doi.org/10.1016/j.jmapro.2019.02.014

Mijović, J., & Zhang, H. (2004). Molecular dynamics simulation study of motions and interactions of water in a polymer network. *Journal of Physical Chemistry B*, *108*(8), 2557–2563. https://doi.org/10.1021/jp036181j

Moriche, R., Prolongo, S. G., Sánchez, M., Jiménez-Suárez, A., Sayagués, M. J., & Ureña, A. (2015). Morphological changes on graphene nanoplatelets induced during dispersion into an epoxy resin by different methods. *Composites Part B: Engineering*, *72*, 199–205. https://doi.org/10.1016/j.compositesb.2014.12.012

Mubashar, A., Ashcroft, I. A., Critchlow, G. W., & Crocombe, A. D. (2009). Moisture absorption-desorption effects in adhesive joints. *International Journal of Adhesion and Adhesives*, *29*(8), 751–760. https://doi.org/10.1016/j.ijadhadh.2009.05.001

Müller, M., & Valášek, P. (2010). Adhesive bonds degradation. *Proceedings of the 9th International Scientific Conference "Engineering for Rural Development*, 49–52.

Musto, P., Ragosta, G., & Mascia, L. (2000). Vibrational Spectroscopy Evidence for the Dual Nature of Water Sorbed into Epoxy Resins. *Chemistry of Materials*, *12*(5), 1331–1341. https://doi.org/10.1021/cm9906809

Myslicki, S., Kordy, H., Kaufmann, M., Créac'hcadec, R., & Vallée, T. (2020). Under water glued stud bonding fasteners for offshore structures. *International Journal of Adhesion and Adhesives*, *98*, 0–8. https://doi.org/10.1016/j.ijadhadh.2019.102533

Nayak, R. K., & Ray, B. C. (2018). Influence of seawater absorption on retention of mechanical properties of nano-TiO2 embedded glass fiber reinforced epoxy polymer matrix composites. *Archives of Civil and Mechanical Engineering*, *18*(4), 1597–1607. https://doi.org/10.1016/j.acme.2018.07.002

Neto, A. S., Da Cruz, D. T. L., & Ávila, A. F. (2013). Nano-modified adhesive by graphene: The single lap-joint case. *Materials Research*, *16*(3), 592–596. https://doi.org/10.1590/S1516-14392013005000022

Obradović, V., Simić, D., Sejkot, P., Machalická, K. V., & Vokáč, M. (2021). Moisture absorption characteristics and effects on mechanical properties of Kolon/epoxy composites. *Current Applied Physics*. https://doi.org/10.1016/j.cap.2021.03.015

Osman, A., Elhakeem, A., Kaytbay, S., & Ahmed, A. (2021). Thermal, electrical and mechanical properties of graphene/nano-alumina/epoxy composites. *Materials Chemistry and Physics*, *257*(August 2020), 123809. https://doi.org/10.1016/j.matchemphys.2020.123809

Oudad, W., Madani, K., Bachir Bouiadjra, B., Belhouari, M., Cohendoz, S., Touzain, S., Feaugas, X., & Oudad W. Bachir Bouiadjra B., Belhouari M., Cohendoz S., Touzain S., Feaugas X., M. K. (2012). Effect of humidity absorption by the adhesive on the performances of bonded composite repairs in aircraft structures. *Composites Part B: Engineering*, *43*(8), 3419–3424. https://doi.org/10.1016/j.compositesb.2012.01.028

Pandiyan, S., Krajniak, J., Samaey, G., Roose, D., & Nies, E. (2015). A molecular dynamics study of water transport inside an epoxy polymer matrix. *Computational Materials Science*, *106*, 29–37. https://doi.org/10.1016/j.commatsci.2015.04.032

Park, S. W., Kim, B. C., & Lee, D. G. (2009). Tensile strength of joints bonded with a nano-particle-reinforced adhesive. *Journal of Adhesion Science and Technology*, *23*(1), 95–113. https://doi.org/10.1163/156856108X344063

Pawlik, M., Lu, Y., & Le, H. (2020). Effects of surface modification and graphene nanoplatelet reinforcement on adhesive joint of aluminium alloys. *International Journal of Adhesion and Adhesives*, *99*(January), 102591. https://doi.org/10.1016/j.ijadhadh.2020.102591

Petersen, R. (2016). Carbon Fiber Biocompatibility for Implants. *Fibers*, *4*(4), 1. https://doi.org/10.3390/fib4010001

Prolongo, S. G., Gude, M. R., & Ureña, A. (2012). Water uptake of epoxy composites reinforced with carbon nanofillers. *Composites Part A: Applied Science and Manufacturing*, *43*(12), 2169–2175. https://doi.org/10.1016/j.compositesa.2012.07.014

Prolongo, S. G., Jiménez-Suárez, A., Moriche, R., & Ureña, A. (2018). Influence of thickness and lateral size of graphene nanoplatelets on water uptake in epoxy/graphene nanocomposites. *Applied Sciences*, *8*(9), 1550. https://doi.org/10.3390/app8091550

Prolongo, S. G., Moriche, R., Jiménez-Suárez, A., Sánchez, M., & Ureña, A. (2014). Advantages and disadvantages of the addition of graphene nanoplatelets to epoxy resins. *European Polymer Journal*, *61*, 206–214. https://doi.org/10.1016/j.eurpolymj.2014.09.022

Prusty, R. K., Rathore, D. K., & Ray, B. C. (2017). CNT/polymer interface in polymeric composites and its sensitivity study at different environments. In *Advances in Colloid and Interface Science* (Vol. 240, pp. 77–106). Elsevier B.V. https://doi.org/10.1016/j.cis.2016.12.008

Quan, D., Carolan, D., Rouge, C., Murphy, N., & Ivankovic, A. (2018). Mechanical and fracture properties of epoxy adhesives modified with graphene nanoplatelets and rubber particles. *International Journal of Adhesion and Adhesives*, *81*(November 2017), 21–29. https://doi.org/10.1016/j.ijadhadh.2017.09.003

Rathore, D. K., Singh, B. P., Mohanty, S. C., Prusty, R. K., & Ray, B. C. (2016). Temperature dependent reinforcement efficiency of carbon nanotube in polymer composite. *Composites Communications*, *1*, 29–32. https://doi.org/10.1016/j.coco.2016.08.002

Ratner, B. (2009). The correlation coefficient: Its values range between +1/−1, or do they? *Journal of Targeting, Measurement and Analysis for Marketing*, *17*(2), 139–142. https://doi.org/10.1057/jt.2009.5

Ray, B. C., & Rathore, D. (2014). Durability and integrity studies of environmentally conditioned interfaces in fibrous polymeric composites: Critical concepts and comments. In *Advances in Colloid and Interface Science* (Vol. 209, pp. 68–83). Elsevier B.V. https://doi.org/10.1016/j.cis.2013.12.014

Razavi, S. M. J. J., Ayatollahi, M. R., Nemati Giv, A., & Khoramishad, H. (2018). Single lap joints bonded with structural adhesives reinforced with a mixture of silica nanoparticles and multi walled carbon nanotubes. *International Journal of Adhesion and Adhesives*, *80*(November 2017), 76–86. https://doi.org/10.1016/j.ijadhadh.2017.10.007

Rider, A. N., Brack, N., Andres, S., & Pigram, P. J. (2004). The influence of hydroxyl group concentration on epoxy–aluminium bond durability. *Journal of Adhesion*

Science and Technology, *18*(10), 1123–1152. https://doi.org/10.1163/1568561041581298

Sadeghi, M. Z., Weiland, J., Zimmermann, J., Schiebahn, A., Reisgen, U., & Schröder, K. U. (2020). Experimental and FE investigations on the influential parameters in positioning and measurement of strain gauges in adhesively bonded single lap joints. *Procedia Structural Integrity*, *28*, 1590–1600. https://doi.org/10.1016/j.prostr.2020.10.131

Saha, S., & Bal, S. (2018). Long term hydrothermal effect on the mechanical and thermo-mechanical properties of carbon nanofiber doped epoxy composites. *Journal of Polymer Engineering*, *38*(3), 251–261. https://doi.org/10.1515/polyeng-2017-0037

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*, *0123456789*. https://doi.org/10.1007/s13738-018-1357-4

Salom, C., Prolongo, M. G., Toribio, A., Martínez-Martínez, A. J., de Cárcer, I. A., & Prolongo, S. G. (2018). Mechanical properties and adhesive behavior of epoxy-graphene nanocomposites. *International Journal of Adhesion and Adhesives*, *84*(November 2017), 119–125. https://doi.org/10.1016/j.ijadhadh.2017.12.004

Saraç, İ., Adin, H., & Temiz, Ş. (2019). Investigation of the effect of use of Nano-Al 2 O 3 , Nano-TiO 2 and Nano-SiO 2 powders on strength of single lap joints bonded with epoxy adhesive. *Composites Part B: Engineering*, *166*(January), 472–482. https://doi.org/10.1016/j.compositesb.2019.02.007

Singh, A. K., Panda, B. P., Mohanty, S., Nayak, S. K., Gupta, M. K., Mohanty, · Smita, Nayak, S. K., Gupta, M. K., Mohanty, S., Nayak, S. K., & Gupta, M. K. (2017). Study on metal decorated oxidized multiwalled carbon nanotube (MWCNT) - epoxy adhesive for thermal conductivity applications. *Journal of Materials Science: Materials in Electronics*, *28*(12), 8908–8920. https://doi.org/10.1007/s10854-017-6621-3

Soles, C. L., Chang, F. T., Gidley, D. W., & Yee, A. F. (2000). Contributions of the nanovoid structure to the kinetics of moisture transport in epoxy resins. *Journal of Polymer Science, Part B: Polymer Physics*, *38*(5), 776–791. https://doi.org/10.1002/(SICI)1099-0488(20000301)38:5<776::AID-POLB15>3.0.CO;2-A

Solomon, M. M., Umoren, S. A., Israel, A. U., & Ebenso, E. E. (2015). Polypropylene Glycol-Silver Nanoparticle Composites: A Novel Anticorrosion Material for Aluminum in Acid Medium. *Journal of Materials Engineering and Performance*, *24*(11), 4206–4218. https://doi.org/10.1007/s11665-015-1716-6

SpecialChem. (2019). *Epoxy Resins for Adhesives and Sealants* . https://adhesives.specialchem.com/selection-guide/epoxy-resins-for-adhesives-and-sealants

Starkova, O., Buschhorn, S. T., Mannov, E., Schulte, K., & Aniskevich, A. (2013). Water transport in epoxy/MWCNT composites. *European Polymer Journal*, *49*(8), 2138–2148. https://doi.org/10.1016/j.eurpolymj.2013.05.010

Starkova, O., Chandrasekaran, S., Prado, L. A. S. A., Tölle, F., Mülhaupt, R., & Schulte, K. (2013). Hydrothermally resistant thermally reduced graphene oxide and multi-wall carbon nanotube based epoxy nanocomposites. *Polymer Degradation and Stability*, *98*(2), 519–526. https://doi.org/10.1016/j.polymdegradstab.2012.12.005

Starkova, O., Chandrasekaran, S., Schnoor, T., Sevcenko, J., & Schulte, K. (2019). Anomalous water diffusion in epoxy/carbon nanoparticle composites. *Polymer Degradation and Stability*, *164*, 127–135. https://doi.org/10.1016/j.polymdegradstab.2019.04.010

Startsev, V. O., Lebedev, M. P., Khrulev, K. A., Molokov, M. V., Frolov, A. S., & Nizina, T. A. (2018). Effect of outdoor exposure on the moisture diffusion and mechanical properties of epoxy polymers. *Polymer Testing*, *65*(December), 281–296. https://doi.org/10.1016/j.polymertesting.2017.12.007

Tam, L. H., & Wu, C. (2017). Molecular mechanics of the moisture effect on epoxy/carbon nanotube nanocomposites. *Nanomaterials*, *7*(10). https://doi.org/10.3390/nano7100324

Tang, L. C., Wan, Y. J., Peng, K., Pei, Y. B., Wu, L. Bin, Chen, L. M., Shu, L. J., Jiang, J. X., & Lai, G. Q. (2013). Fracture toughness and electrical conductivity of epoxy composites filled with carbon nanotubes and spherical particles. *Composites Part A: Applied Science and Manufacturing*, *45*, 95–101. https://doi.org/10.1016/j.compositesa.2012.09.012

Tang, L. C., Wan, Y. J., Yan, D., Pei, Y. B., Zhao, L., Li, Y. B., Wu, L. Bin, Jiang, J. X., & Lai, G. Q. (2013). The effect of graphene dispersion on the mechanical properties of graphene/epoxy composites. *Carbon*, *60*, 16–27.

https://doi.org/10.1016/j.carbon.2013.03.050

Tiwari, S. K., Sahoo, S., Wang, N., & Huczko, A. (2020). Graphene research and their outputs: Status and prospect. *Journal of Science: Advanced Materials and Devices*, *5*(1), 10–29. https://doi.org/10.1016/j.jsamd.2020.01.006

Tomasi, J. M., Helman, I. D., Pisani, W. A., Klimek-McDonald, D. R., Chinkanjanarot, S., Miskioglu, I., King, J. A., & Odegard, G. M. (2016). Accelerated hydrothermal aging of cycloaliphatic epoxy/graphene nanoparticle composites. *Polymer Degradation and Stability*, *133*, 131–135. https://doi.org/10.1016/j.polymdegradstab.2016.08.009

Tutunchi, A., Kamali, R., & Kianvash, A. (2015). Steel-Epoxy Composite Joints Bonded with Nano-TiO2 Reinforced Structural Acrylic Adhesive. *Journal of Adhesion*, *91*(9), 663–676. https://doi.org/10.1080/00218464.2014.961187

Tutunchi, A., Kamali, R., & Kianvash, A. (2016). Effect of Al2O3 nanoparticles on the steel-glass/epoxy composite joint bonded by a two-component structural acrylic adhesive. *Soft Materials*, *14*(1), 1–8. https://doi.org/10.1080/1539445X.2014.1003269

Utumi, M. V., Corso, L. L., & Gasparin, A. L. (2021). New method to distinguish adhesion and cohesion stresses in metal/polymer composites. *Materials Research*, *24*(2). https://doi.org/10.1590/1980-5373-MR-2020-0277

Viana, G., Costa, M., Banea, M. D., Silva, L. F. M., & Da Silva, L. F. M. (2016). A review on the temperature and moisture degradation of adhesive joints. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials Design and Applications*, *231*(5), 488–501. https://doi.org/10.1177/1464420716671503

Waite, J. H. (1987). Nature's underwater adhesive specialist. *International Journal of Adhesion and Adhesives*, *7*(1), 9–14. https://doi.org/10.1016/0143-7496(87)90048-0

Failure criteria, Bonded Joints and Repairs to Composite Airframe Structures 21 (2016).

Wang, G., Liu, L., & Zhang, Z. (2021). Interface mechanics in carbon nanomaterials-based nanocomposites. *Composites Part A: Applied Science and Manufacturing*, *141*, 106212. https://doi.org/10.1016/j.compositesa.2020.106212

Wang, X., Qi, X., Lin, Z., & Battocchi, D. (2018). Graphene reinforced composites as protective coatings for oil and gas pipelines. *Nanomaterials*, *8*(12). https://doi.org/10.3390/nano8121005

Wang, Y., Meng, Z., Zhu, W., Wan, B., Han, B., Cai, G., Yin, X., & Bai, Y. (2021). Hygrothermal aging behavior and aging mechanism of carbon nanofibers/epoxy composites. *Construction and Building Materials*, *294*, 123538. https://doi.org/10.1016/j.conbuildmat.2021.123538

Wang, Z., Jia, Z., Feng, X., & Zou, Y. (2018). Graphene nanoplatelets/epoxy composites with excellent shear properties for construction adhesives. *Composites Part B: Engineering*, *152*, 311–315. https://doi.org/10.1016/j.compositesb.2018.08.113

Wei, H., Xia, J., Zhou, W., Zhou, L., Hussain, G., Li, Q., & Ostrikov, K. (Ken). (2020). Adhesion and cohesion of epoxy-based industrial composite coatings. *Composites Part B: Engineering*, *193*(December 2019), 108035. https://doi.org/10.1016/j.compositesb.2020.108035

Wu, R., Huang, Y., Xu, J., Rong, Y., & Chen, Q. (2022). Stress and distortion of the 10 mm thick plate EH40 and 316L different butt joints in 10 kW laser welding. *Optics and Laser Technology*, *152*(March), 108179. https://doi.org/10.1016/j.optlastec.2022.108179

Xie, Y., Zhang, J., & Zhou, T. (2019). Large-area mechanical interlocking via nanopores: Ultra-high-strength direct bonding of polymer and metal materials. *Applied Surface Science*, *492*(June), 558–570. https://doi.org/10.1016/j.apsusc.2019.06.246

Yadav, S. K., & Cho, J. W. (2013). Functionalized graphene nanoplatelets for enhanced mechanical and thermal properties of polyurethane nanocomposites. *Applied Surface Science*, *266*, 360–367. https://doi.org/10.1016/j.apsusc.2012.12.028

Yang, C., Xing, X., Li, Z., & Zhang, S. (2020). A comprehensive review on water diffusion in polymers focusing on the polymer-metal interface combination. *Polymers*, *12*(1), 138. https://doi.org/10.3390/polym12010138

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. (2011). 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

Yu, Z., Lv, L., Di, H., & He, Y. (2016). *Covalent modification of graphene oxide by metronidazole for reinforce anti-corrosion of epoxy coatings*. https://doi.org/10.1039/C5RA23595B

Zaeri, A. R., & Saeidi Googarchin, H. (2019). Experimental investigation on environmental degradation of automotive mixed-adhesive joints. *International Journal of Adhesion and Adhesives*, *89*, 19–29. https://doi.org/10.1016/j.ijadhadh.2018.11.008

Zhang, C., Sun, L., Huang, B., Yang, X., Chu, Y., & Zhan, B. (2019). Electrical and mechanical properties of CNT/CB dual filler conductive adhesives (DFCAs) for automotive multi-material joints. *Composite Structures*, *225*(June), 111183. https://doi.org/10.1016/j.compstruct.2019.111183

Zhang, J., Li, H.-Y., Li, H., & Jia, H. (2020). Investigation on fatigue performance of adhesively bonded butt-joints and multiaxial life estimation using stress-based failure models. *Theoretical and Applied Fracture Mechanics*, *107*, 102498. https://doi.org/10.1016/j.tafmec.2020.102498

Zhao, S., Schadler, L. S., Duncan, R., Hillborg, H., & Auletta, T. (2008). Mechanisms leading to improved mechanical performance in nanoscale alumina filled epoxy. *Composites Science and Technology*, *68*(14), 2965–2975. https://doi.org/10.1016/j.compscitech.2008.01.009

Zhao, X., Fan, Y., Liu, Y., Wang, H., & Dong, P. (2015). Evaluation of fatigue fracture mechanism in a flash butt welding joint of a U75V type steel for railroad applications. *Engineering Failure Analysis*, *55*, 26–38. https://doi.org/10.1016/j.engfailanal.2015.05.001

Zhou, H. H. H., Liu, H. Y., Zhou, H. H. H., Zhang, Y., Gao, X., & Mai, Y. W. (2016). On adhesive properties of nano-silica/epoxy bonded single-lap joints. *Materials and Design*, *95*, 212–218. https://doi.org/10.1016/j.matdes.2016.01.055

Zou, H., Wu, S., & Shen, J. (2008). Polymer/Silica Nanocomposites: Preparation, characterization, propertles, and applications. *Chemical Reviews*, *108*(9), 3893–3957. https://doi.org/10.1021/cr068035q