Iraqi Journal of Physics, 2022 *Vol.20, No. 2, PP.1-10*
DOI: 10.30723/ijp.v20i2.982 *P-ISSN: 2070-4003*
E-ISSN: 2664-5548

Enhanced Mechanical Property of Acrylic Polymer/Graphene/Carbon Fibers Hybrid for Water Proof Coating

Tabarak M. Abbas[*a], Seenaa I. Hussein[b]
Department of Physics, College of Science, University of Baghdad,
[b]E-mail: seenaa.hussein@sc.uobaghdad.edu.iq
[*a]Corresponding author: tabarak.maher1204a@sc.uobaghdad.edu.iq

Abstract
In this work, some mechanical properties of the polymer coating were improved by preparing a hybrid system containing Graphene (GR) of different weight percentages (0.25, 0.5, 1, and 2wt%) with 5wt% carbon fibres (CF) and added to a polymer coating by using casting method. The properties were improved as GR was added with further improvement on adding 5wt% of CF. The impact strength of acrylic polymer with GR increases with increasing weight ratio of GR; maximum value was obtained when the polymer coating was incorporated with 1wt% GR and 5wt% CF. The impact strength of acrylic polymer with GR and GR/CF composites incorporated with GR at 1wt% and CF at 5wt%. Hardness increase with increasing weight ratio of Gr and a significant improvement was observed at 1wt% GR and 5wt% CF content. The tensile strength increases more significantly than the acrylic polymer with GR and GR/CF composites incorporated with GR at 1wt% and CF at 5wt%. Pull-off strength for the polymer coating with GR and CF was greater than for the acrylic polymer coating.

Article Info.

Keywords:
Acrylic polymer, SEM, Graphene, carbon fiber, mechanical properties.

Article history:
Received: Feb. 24, 2022
Accepted: Apr. 20, 2022
Published: Jun. 01,2022

1. Introduction
In general, all materials may have failures due to different reasons such as external weathering, abrasion, chemical effects of water, and heat effects which may happen directly after involved in the application or after long time turn of application. Coatings of surfaces represent an optimum solution for the mentioned problem; however, coatings can also have malfunctions delete caused at any time during application[1]. The coating surface is thin composite materials consisting of bonding materials, organic polymers, with a variety of different components, in addition to dyes, solvents, water and other additives that are distributed in case of powder coatings, they are applied directly to the substrates in case of organic bonds [2]. One of the used systems in material science is composite materials, which are engaged in various applications, such as transportation [3], building materials [4], thermal management [5] and energy storage [6]. Composite systems are materials resulting from mixing or blending two or more materials to obtain a new substance [7] that differs significantly in mechanical or physical properties [8, 9]. They are of different type varieties, including: hybrid composites, which combine organic and inorganic components; these are commonly employed in coatings applications [10].

Thus, hybrid materials are nanocomposites which contain at least one element which may be organic or inorganic [11]. They can be divided into two main parts, which contain components of organic materials and inorganic materials depending on the nature of the interface [12]. The first section is the organic and inorganic materials that work with weak bonds, such as Van der Waals and hydrogen bonds, and the second section in which the components are connected with covalent chemical or ionic covalent bonds [13]. The two components making up a composite are the basic material which is the large content, and the other is called the reinforcing material (filler) of smaller percentage.

Composite materials have found their way into coatings systems, whereby using a coating system consisting of composite materials for a specific substrate can improve the mechanical properties of the substrates [14]. Polymer nanocomposites have been manufactured and some of their properties have been improved by introducing nanoscale inorganic compounds [8, 9]. Graphene nanomaterial has been used to reinforce coating materials and to improve mechanical properties, thermal and improve the ability to conduct heat and electricity [10]. Carbon fibers have also been used to reinforce polymers, which is involved in many applications, especially coating materials due to its brilliant quality and high mechanical and thermal properties [10]. Wettability can be indicated through determining the contact angle. When the contact angle is less than 90, the paint is known as hydrophilic, and when the contact angle is greater than 90, the paint is known as hydrophobic [15].

Abdullah and Ansari (2014) studied the dispersion of graphene on the epoxy coating, the contact angle of water droplets on a sample surface was increased from ∼82° to ∼127° (hydrophobic epoxy and graphene) [16].

Salahuddin, et al. (2021) studied the carbon fiber reinforced polymer composites that make them ideal engineering materials to with stand loads and stresses. Coupling the fiber and matrix together requires a good understanding of not only fiber morphology but also matrix rheology. One method of having a strongly coupled matrix and fiber interface is to quantify the reinforcing fibers by coating carbon micro or nanomaterials on the surface of the fibers [17].

The objective of the present work is to improve some mechanical properties of polymer coating. Graphene **(**GR) of different weight percentages (0.25, 0.5, 1, and 2 wt%) and 5wt% carbon fibres (CF) were added to a polymer coating, which is used in floors coating, using the casting method.

2. Experimental work

2.1. Materials

Acrylic polymer, density (1.7 kg/L), was purchased from Al Gurg Forsroc LLC Company, United Arab Emirates. Graphene and carbon fiber were purchased from sika top seal Dubai, U.A.E – Fig.1 depicts how the surface structure of Gr nano using atomic force microscopy. It has been observed that the average diameter of GR was 59.22nm.

2.2. Preparing of samples acrylic polymer coating and acrylic polymer / Graphene / Chopped carbon fibers

The acrylic polymer/GR and acrylic polymer/GR/CF hybrid were prepared using the casting technique. The acrylic polymer solution and GR, and CF filler were made by weighing 100 g and then were cast before the drying process for 24 h at room temperature. To achieve a homogeneous polymer composite, GR and CF fillers were dissolved in acetone before being mixed with the acrylic polymer. The ratios of

GR were equal to 0.25, 0.5, 1, 2 wt%, while, the ratio of CF was kept constant at 5 wt%. Then the proposed ratios of the filler were added to the acrylic polymer solution. The mixture solution was put in a glass tube on a magnetic stirrer at room temperature for 1 h. Fig. 2 depicts the optical images of the acrylic polymer/GR nanocomposites and acrylic polymer/GR/CF hybrids.

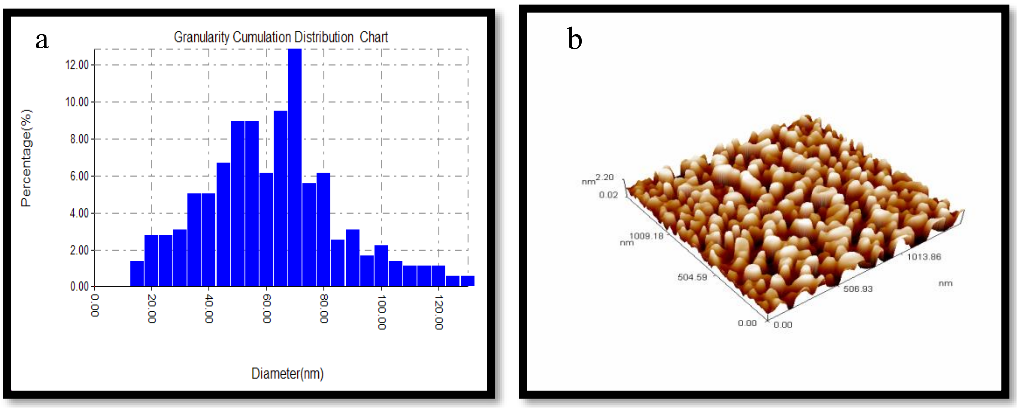

Figure 1: (a) normal distribution of granules and (b) three -dimensional image for GR nanoparticles used in the work.

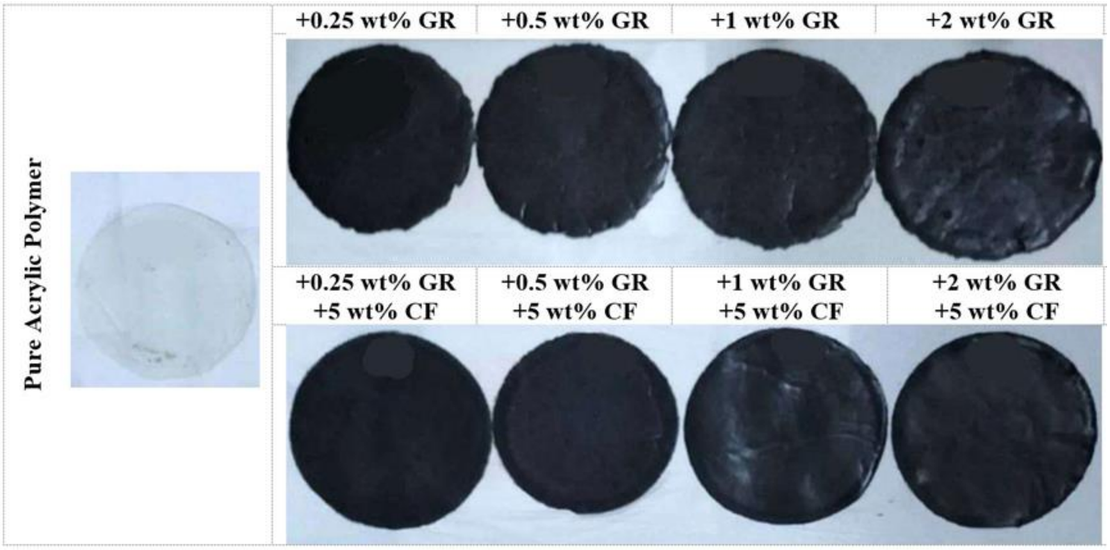

Figure 2: Optical images of pure acrylic polymer, acrylic polymer/GR composites, and acrylic polymer/GR/CF hybrids.

2.3. Mortar substrate

The mortar (cement) substrate samples were prepared in cement (Portland) forms measuring 4 cm, 50 g weight of cement was mixed with 10 ml water, mixing time was 5 min. 2 ml of epoxy was added for the materials. They were previously testes for pull off adhesion test.

2.4. Mechanical tests

Impact strength: The impact strength was determined using the drop tester IDM-P0007 by estimating the minimum height from which the 20 mm diameter impactor falls, producing mechanical damage to the coating. Impact with a 2 kg impactor from a height of 1 m was performed in the test.

Hardness: The hardness of the cured material was determined using Shore A durometer model HT-6510A. The hardness of the sample was tested more than ten times at various locations on its surface, and the average values were estimated. The softest durometer is penetration, which measures a material's resistance to penetration or scratching.

Tensile strength: The tensile test was performed on flat specimens. Tensile tests were performed on intronLaryee at affixed crosshead speed of 5mm/min samples were prepared according to ASTM D638. Testing machine make was Shimadzu –Japan, randeof machine was 1-100 KN

Adhesion strength: The coating-substrate adhesion was measured using PosiTest AT adhesion tester it is a compact, hand-operated device that tests the force necessary to draw a specific test size of coatings out of its substrate under increased hydraulic pressure. The coating's degree of adhesion to the substrate is represented by the pressure, which is shown on a digital LCD. The standard specification are D4541 and D7234.

2.5. Scanning Electron Microscope

A scanning electron microscope (SEM) model (MIRAIII), (TESCAN), (Czech Republic made) was used to investigate the surface morphology of the polymer composite samples. The polymer composites and hybrids samples were sputter-coated with gold before the SEM examination to avoid charge buildup.

3- Results and discussion

3.1. Impact test

Fig. 3 shows that the impact strength of acrylic polymer (coating) with GR increases with the increase weight ratio of GR. This was further increased when 5wt% CF was added to the acrylic polymer/GR nanocomposite, showing a maximum value at 1wt% GR. This it may be due to the geometry (larger surface area) of GR nanocomposite which results in good matrix-reinforcement bonding. GR and CF ability as reinforcing materials comes from the residual groups of hydroxyl and acrylic polymer on their surface. The interstitial adhesion between matrix and fiber was improved by micromechanical interlocking and covalent bonding with acrylic polymer matrices, resulting in superior mechanical efficiency of GR and CF containing composites [18]. It indicates that GR and CF have a more important effect on the impact strength acrylic polymer.

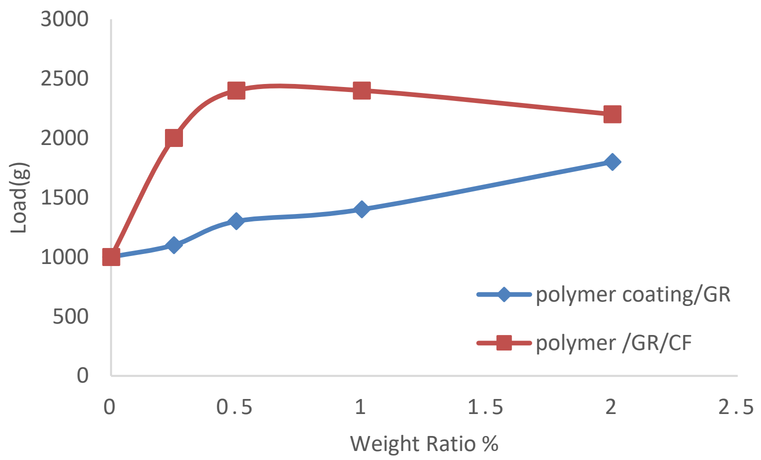

Figure 3: Impact strength of polymer coating pure, acrylic polymer / GR and acrylic polymer / GR/CF.

3.2. Hardness test

Fig.4 shows the improvement in hardness of the polymer coating at different GR and CF content, as a result of a super interaction between GR molecules with polymer matrix. Hardness increases with the increase of weight ratio good dispersion of lead particles: a significant improvement in the properties was observed at 1wt% GR and 5% CF. The mechanical properties of polymer composites can be altered by various factors such as particle distribution and loading, surface adhesion between the matrix and filler particle size and formation of filler particles [19], the decrease of hardness at 2wt% GR and CF is because of the accumulation of particles at the high content of GR causing a decrease in the surface area of the particles, thus reducing the adhesion and forming a separate phase in the polymer matrix.

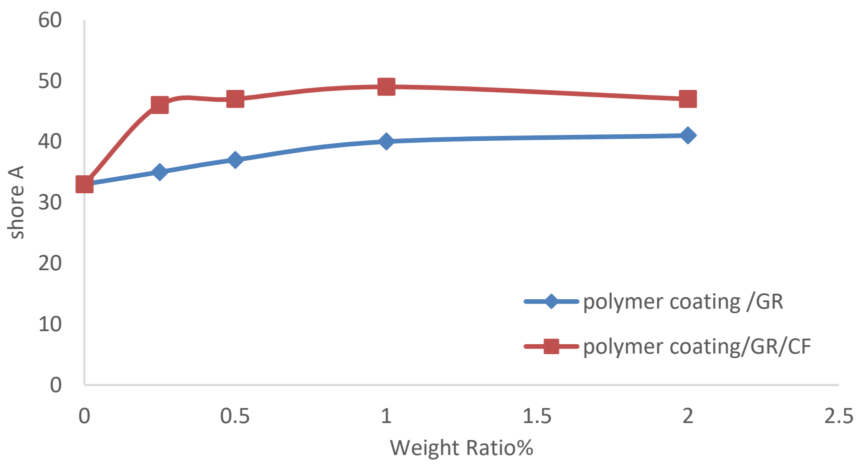

Figure 4: Hardness shore (A) of acrylic polymer / GR and acrylic polymer / GR/CF.

3.3. Tensile strength

Fig.5 shows the tensile strength of acrylic polymer composites and hybrids. It was observed the tensile strength of acrylic polymer composite was increased as the weight ratio of GR was increased. It is worth noting, that the change in the strength of acrylic polymer hybrids shows different behaviors compared to acrylic polymer composite. It was observed that the tensile strength was increased as the GR ratio was increased up to 1 wt%, and then was decreased for a further increase in the GR ratio. The decrease in the tensile strength for a further increase in the GR content may be attributed to the geometry (greater surface area) of GR nanoparticles which promotes effective matrix-reinforcement bonding [20]. Where the strength of the nano composites is improved instead of the matrix material due to the strengthening of GR and CF. It was noted that the tensile strength acrylic polymer/GR/CF is greater than that of the acrylic polymer with GR. Micromechanical interlocking and covalent bonding with acrylic polymer matrices increase the interstitial adhesion between matrix and fiber, resulting in the higher mechanical efficiency of GR and CF containing hybrids [21].

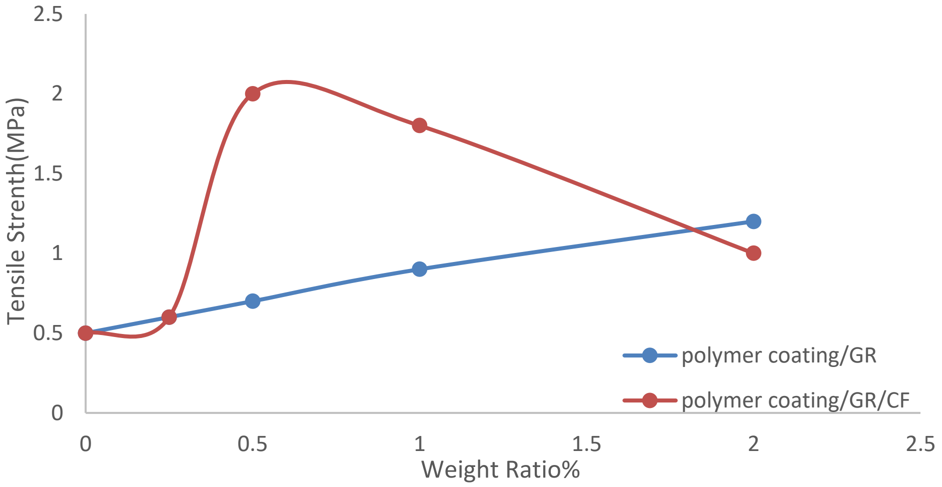

Figure 5: Tensile strength of acrylic polymer / GR and acrylic polymer / GR/CF.

3.4. Adhesion pull off strength

Figs. 6 and 7 shows the adhesion strength changes with the weight ratio of GR with and without CF. The values of squeeze strength for the polymeric coating with GR were higher than for the polymer coating. Polymer coating to GR results in a higher pull-off strength as the weight ratio of GR increases. These values were increased further as CF was added. GR adherence to carbon fiber surface has improved. The results showed maximum value at 1wt% GR with and without CF. Coatings resulted in a squeeze strength greater than 205MPa (again for polymer coating), which agrees with the results of Szymanowski [22]. As a result, the CF – GR interface qualities have substantially improved. At the contact between CF and GR, a continuous phase forms, and the depth of the substrates at the carbon fiber contact surface has increased, increasing the bonding strength of carbon fiber as well as the substrate. Finally, the carbon fiber under load in concrete cannot be readily pulled out, allowing the full potential of carbon fiber to be realized. GR particles can be incorporated into a polymer to enable bonding and establish new chemical interactions which would not be triggered by the polymer.

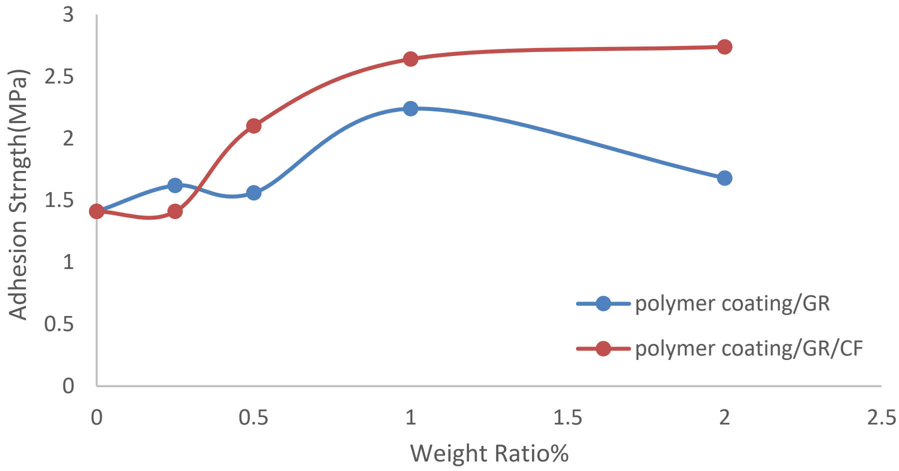

Figure 6: Adhesion strength of acrylic polymer / GR and acrylic polymer / GR/CF.

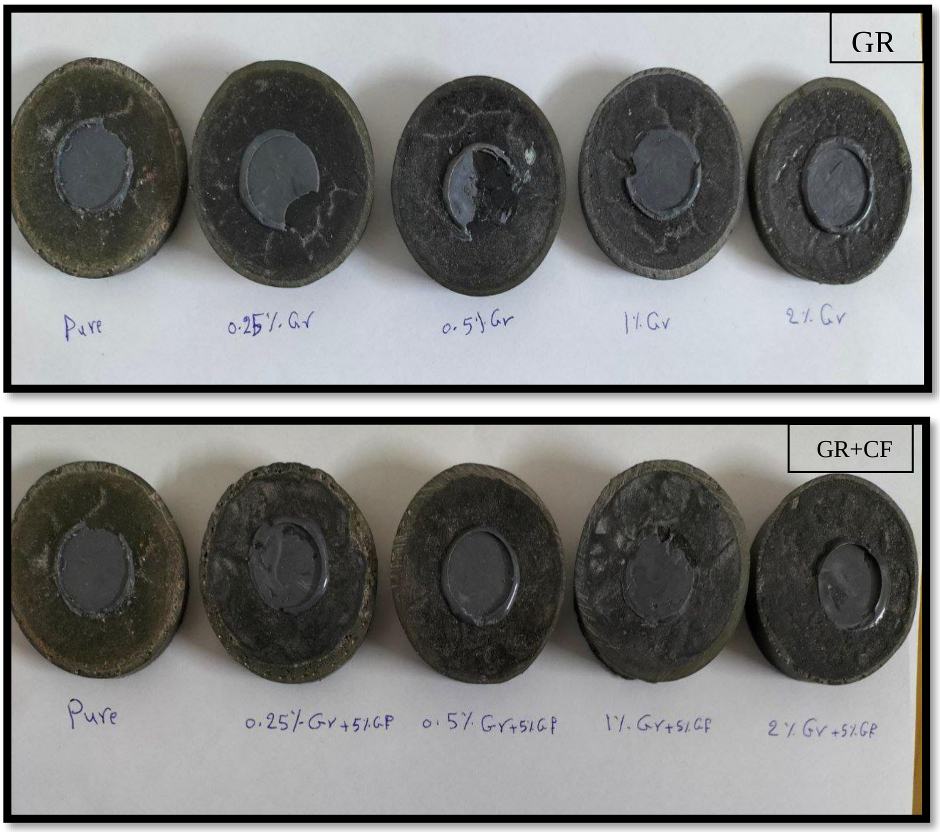

Figure 7: Samples after the adhesion strength test a- Acrylic polymer /GR b- acrylic polymer / GR/ CF.

4. Scanning Electron Microscope (SEM)

Fig. 8 shows the selected SEM images of acrylic polymer composites doped with 0.25 wt% GR, and acrylic polymer hybrids doped with 0.25 wt% GR + 5 wt% CF. The SEM images for acrylic polymer composites containing 0.25 wt% GR reveal the presence of small spherical particles inside the matrix with a homogenous distribution [23]. The average particle size of the GR was estimated to be 28.5 nm. On the other side, the SEM images for acrylic polymer hybrids doped with 0.25 wt% GR + 5 wt% CF reveals the presence of platelet shape besides the spherical nanoparticles in the polymer matrix. The observed platelet shapes could belong to the CF, and their average estimated width was closed to 75.1 nm.

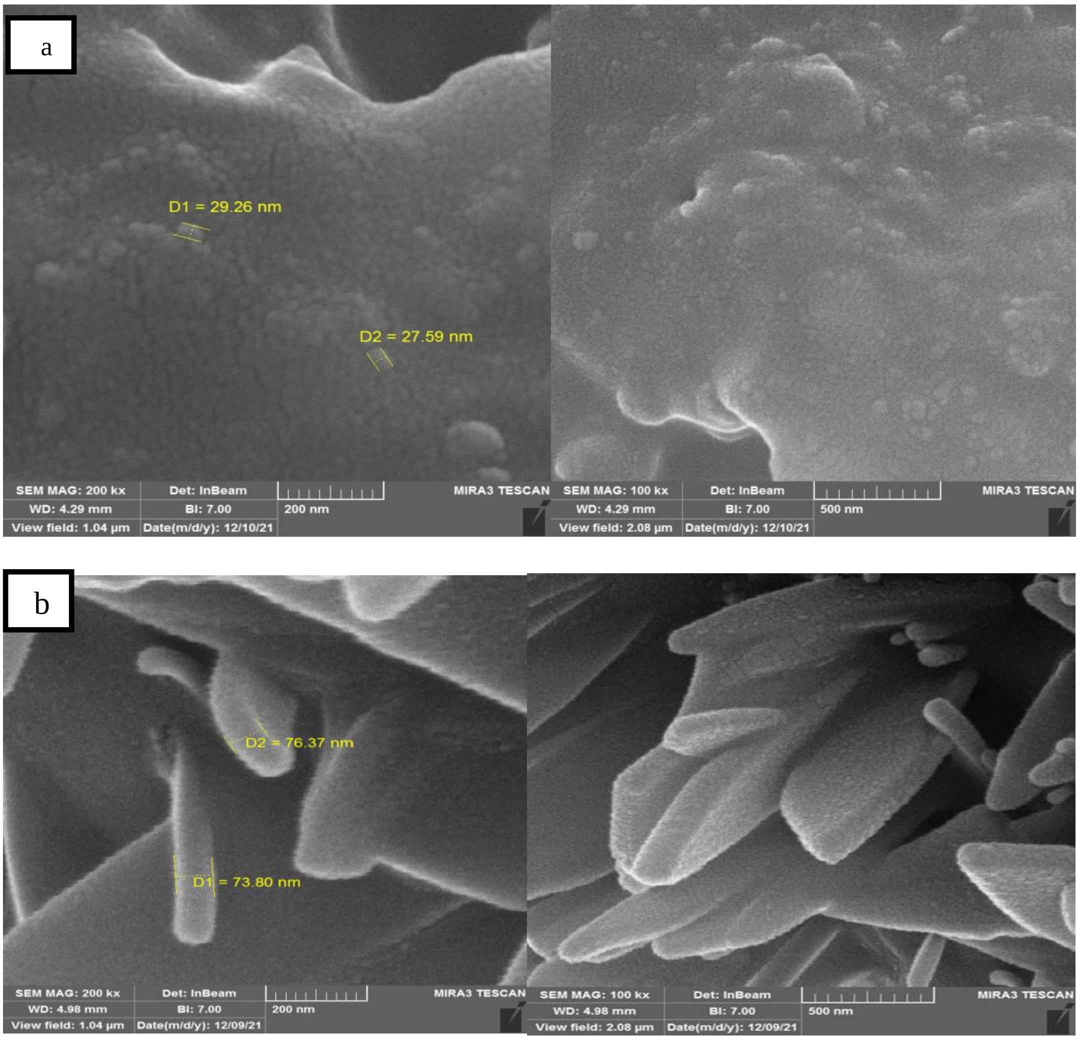

Figure 8: SEM images of acrylic polymer composites doped with (a) 0.25 wt% GR, and acrylic polymer hybrids doped with (b) 0.25 wt% GR + 5 wt% CF.

5. Conclusion

Adding GR to polymeric coating has improved its mechanical properties: impact strength, hardness tensile strength and adhesion strength. These were further improved on adding 5wt% of CF. The results showed maximum values of impact strength and hardness when 1wt% GR with 5wt% CF were added to the acrylic polymer. The tensile strength showed maximum values when 0.5wt% GR with 5wt% CF were added to the acrylic polymer. While, the adhesion strength showed maximum value at 2wt% GR with 5wt% CF.

Acknowledgments

The authors acknowledge the Packaging Center, Ministry of Industry and Minerals for completing this research work.

Conflict of interest

Authors declare that they have no conflict of interest.

References

1. Paul J.G., *Introduction to coating and paints* 2010, American socity of civil Engineers, Continuing Education and Development.
2. Palmieri F.L., Ledesma R.I., Dennie J.G., Kramer T.J., Lin Y., Hopkins J.W., Wohl C.J., and Connell J.W., *Optimized surface treatment of aerospace composites using a picosecond laser.* Composites Part B: Engineering, 2019. **175**: pp. 1-10.
3. Nguyen K.T., Navaratnam S., Mendis P., Zhang K., Barnett J., and Wang H., *Fire safety of composites in prefabricated buildings: From fibre reinforced polymer to textile reinforced concrete.* Composites Part B: Engineering, 2020. **187**: pp. 1-12.
4. Rohani H., Badakhsh A., and Park C.W., *Thermal performance of modified polymeric heatsinks as an alternative for aluminum in heat rejection systems* . Applied Thermal Engineering, 2019. **159**: pp. 1-10.
5. Abd-Elnaiem A.M., Salman O.S., Hakamy A., and Hussein S.I., *Mechanical Characteristics and Thermal Stability of Hybrid Epoxy and Acrylic Polymer Coating/Nanoclay of Various Thicknesses.* Journal of Inorganic Organometallic Polymers Materials, 2022: pp. 1-9.
6. Balla V.K., Kate K.H., Satyavolu J., Singh P., and Tadimeti J.G.D., *Additive manufacturing of natural fiber reinforced polymer composites: Processing and prospects.* Composites Part B: Engineering :174 .2019 ,pp. 1-29.
7. Sun T., Li M., Zhou S., Liang M., Chen Y., and Zou H., *Multi-scale structure construction of carbon fiber surface by electrophoretic deposition and electropolymerization to enhance the interfacial strength of epoxy resin composites.* Applied Surface Science, 2020. **499**: pp. 1-12.
8. Shen W., Ma R., Du A., Cao X., Hu H., Wu Z., Zhao X., Fan Y., and Cao X., *Effect of carbon nanotubes and octa-aminopropyl polyhedral oligomeric silsesquioxane on the surface behaviors of carbon fibers and mechanical performance of composites.* Applied Surface Science, 2018. **447**: pp. 894-901.
9. Chowaniec A. and Ostrowski K., *Epoxy resin coatings modified with waste glass powder for sustainable construction.* Czasopismo Techniczne, 2018. **2018**: pp. 99-109.
10. Chen J., Wu J., Ge H., Zhao D., Liu C., and Hong X., *Reduced graphene oxide deposited carbon fiber reinforced polymer composites for electromagnetic interference shielding.* Composites Part A: Applied Science Manufacturing, 2016. **82**: pp. 141-150.
11. Tiwari S.K., Kumar V., Huczko A., Oraon R., Adhikari A.D., and Nayak G., *Magical allotropes of carbon: prospects and applications.* Critical Reviews in Solid State Materials Sciences, 2016. **41**(4): pp. 257-317.
12. Ali N.A., Abd-Elnaiem A.M., Hussein S.I., Khalil A.S., Alamri H.R., and Assaedi H.S., *Thermal and Mechanical Properties of Epoxy Resin Functionalized Copper and Graphene Hybrids using In-situ Polymerization Method.* Current Nanoscience, 2021. **17**(3): pp. 494-502.
13. Lu G., Zhao W., and Dai D. *Study on Preparation of cementitious capillary crystalline waterproofing coating*. in *3rd International Conference on Mechatronics, Robotics and Automation*. 2015. Atlantis Press.
14. Wegst U.G., Bai H., Saiz E., Tomsia A.P., and Ritchie R.O., *Bioinspired structural materials.* Nature materials, 2015. **14**(1): pp. 23-36.

15. Hussein S.I., *Preparation and Characterization of Flexible Plastic Packaging Using An Acrylic Polymer Solution.* Malaysian Journal Of Science, 2020: pp. 54-64.
16. Abdullah S.I. and Ansari M., *Mechanical properties of graphene oxide (GO)/epoxy composites.* Hbrc Journal, 2015. **11**(2): pp. 151-156.
17. Salahuddin B., Faisal S.N., Baigh T.A., Alghamdi M.N., Islam M.S., Song B., Zhang X., Gao S., and Aziz S., *Carbonaceous materials coated carbon fibre reinforced polymer matrix composites.* Polymers, 2021. **13**(16): pp. 1-23.
18. Yarlagaddaa J. and Malkapuram R., *Influence of carbon nanotubes/graphene nanoparticles on the mechanical and morphological properties of glass woven fabric epoxy composites.* Incas Bulletin, 2020. **12**(4): pp. 209-218.
19. Abd-Elnaiem A.M., Hussein S.I., Assaedi H.S., and Mebed A., *Fabrication and evaluation of structural, thermal, mechanical and optical behavior of epoxy–TEOS/MWCNTs composites for solar cell covering.* Polymer Bulletin, 2021. **78**(7): pp. 3995-4017.
20. Hussein S.I., Abd-Elnaiem A.M., Asafa T.B., and Jaafar H.I., *Effect of incorporation of conductive fillers on mechanical properties and thermal conductivity of epoxy resin composite.* Applied Physics A, 2018. **124**(7): pp1-9.
21. Wang Z., Huang X., Xian G., and Li H., *Effects of surface treatment of carbon fiber: Tensile property, surface characteristics, and bonding to epoxy.* Polymer Composites, 2016. **37**(10): pp. 2921-2932.
22. Szymanowski J., *Evaluation of the adhesion between overlays and substrates in concrete floors: Literature survey, recent non-destructive and semi-destructive testing methods, and research gaps.* Buildings, 2019. **9**(9): pp. 1-23.
23. He X., Wang Z., Pu Y., Wang D., Tang R., Cui S., Wang J.-X., and Chen J.-F., *High-gravity-assisted scalable synthesis of zirconia nanodispersion for light emitting diodes encapsulation with enhanced light extraction efficiency.* Chemical Engineering Science, 2019. **195**: pp. 1-10.

تحسين الخصائص الميكانيكية لهجين اكريلك بوليمر – كرافيين –الياف الكاربون المستخدم كطلاء عازل للماء

تبارك ماهر عباس، سيناء ابراهيم حسين
قسم الفيزياء، كلية العلوم، جامعة بغداد

الخلاصة

الهدف من الدراسة الحالية هو تحسين بعض الخواص الميكانيكية بأضافة الكرافيين والياف الكاربون المقطعة بنسب وزنية مختلفة الى بوليمر الطلاء واستخدامه في طلاء الارضيات. استخدمت طريقة الصب بتحضير الهجين وتم خلط المواد النانويه بنسب وزنية مختلفة وهي (0.25 و0.5 و1 و2) ونفس النسب السابقه مع 5 % الياف الكاربون المقطعه، هذه الخواص تحسنت بأضافة نسب الكرافيين مع نسبة الياف الكاربون المقطعة .متانة الصدمة للبوليمر الطلاء المدعم باكرافين ازدادت بزيادة النسب الوزنيه للكرافين اما بالنسبه لهجين بوليمر مع الكرافين والياف الكاربون المقطعه كانت افضل نسبه عند 1%، والصلادة بوليمر ازدادت بزيادة النسب الوزنيه للكرافيين وافضل نسبة عند الهجين هي
1%كرافيين مع5% الياف الكاربون المقطعة. متانة الشد ازداد 0.5% كرافين و5% الياف الكاربون. اما متانة الالتصاقية كانت هجين اكريلك بوليمر الطلاء مع كرافيين والياف الكاربون افضل من قيم بوليمر الطلاء.