*Mechanics in Nano-Engineering 1(1) (2027) 100-110*

Ministry of Science, Research and Technology
University of Bonab

**Mechanics in Nano-Engineering**

journal homepage: https://mneng.ubonab.ac.ir/

Mechanics in NANO-ENGINEERING

# Mechanical Properties of Polyvinyl Chloride Composites and Nanocomposites: A Brief Review

Parsa Dabbagh Yarishah [a,*], Leila Farghdan Soltan Ahmadi [b]

[a] Payame Noor University, East Azerbaijan Province, Tabriz, Iran.
[b] Technical Expert, Nano-Sanat Farda Company, Tabriz, Iran.

**ARTICLE INFO**

*Article history:*
Received 09 18 2026
Received in revised form 10 09 2026
Accepted 11 09 2026

*Keywords:*
Composites
Nanocomposites
Polyvinyl chloride
Mechanical properties

**ABSTRACT**

The development of composite materials is a long-standing process that, in light of the needs of society and their wide-ranging applications, is continually growing. From this point of view, the reinforcement of polymeric materials in micro-scale and nanoscale dimensions is considered one of the main objectives in the development of these materials. Nanofillers increase the specific surface area of contact between components and improve the surface-to-volume ratio. These changes lead to the improvement and strengthening of the overall performance of the resulting materials and the promotion of their notable properties. Owing to their suitable mechanical properties, these materials are used in many applications such as the automotive, construction, packaging, and aerospace industries. However, these properties are influenced by numerous factors such as processing conditions, interfacial adhesion between the filler and the matrix, and the extent and manner of their dispersion. In this study, a brief review of numerous investigations in the field of the mechanical properties of polyvinyl chloride (PVC)-based composite and nanocomposite materials has been carried out.

## 1. Introduction

Composite and nanocomposite materials are as old as the world itself. Several thousand years ago, craftsmen in ancient Egypt increased the mechanical properties of bricks by adding straw to clay [1]. Composites are a class of materials consisting of two or more distinct constituents with physical and/or chemical properties that are completely different from one another. The resulting composite can possess mechanical properties improved relative to the matrix, with a new performance. In terms of the type of matrix employed, composites can be divided into three categories: polymer matrix composites (PMC), metal matrix composites (MMC), and ceramic matrix composites (CMC). Most artificial composites use thermosetting resins and polymers, such as unsaturated polyester resin [2], phenolic resin [3], epoxy resin [4], and elastomer [5], as well as thermoplastic polymers such as polyethylene [6], polypropylene [7], polyvinyl chloride [8], and polydiene [9].

* Corresponding author.
E-mail addresses: parsadabbagh@yahoo.com
http://dx.doi.org
© 2027 Published by University of Bonab

Thermoplastics such as polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC) are often used in the construction of composites and nanocomposites [10]. From 2003 to 2010, demand increased by 130% for PP composites, 40% for PE composites, and by approximately 200% for PVC-based materials. Although polyethylene is a widely used polymer, there has been a remarkable increase in PVC-based composites and nanocomposites [11]. In this study, a brief review of numerous investigations in the field of the mechanical properties of polyvinyl chloride (PVC)-based composite and nanocomposite materials has been carried out.

## 2. Mechanical Properties of Composites

Reinforcements in composites can, from a morphological standpoint, be classified according to their physical size into macroscopic, microscopic, and nanometer-scale forms. Conventional composites use macroscopic fiber fabrics or short microscopic fibers as reinforcements. The mechanical properties of composites depend on various parameters, such as the type of additives, the interfacial adhesion between the filler and the matrix, and the size and dispersion of the filler.

Composites with a PVC matrix are widely used across industries because they offer acceptable mechanical properties, chemical resistance and fire resistance, low water absorption, long service life, and resistance to ultraviolet radiation [12]. In 1993, Andersen Corporation carried out the construction of PVC/WF composites for doors and windows using extrusion and injection molding [13]. Laurent et al., in order to obtain PVC with satisfactory and highly efficient productivity, investigated the effects of plasticizers on the properties of PVC composites. According to the results obtained, at lower plasticizer contents, the Young's modulus increases indefinitely due to an anti-plasticization phenomenon, while at higher plasticizer contents, the Young's modulus decreases with increasing plasticizer content [14]. Also, in another investigation, it has been reported that the addition of fibers, owing to their higher modulus, increases the modulus of the composites [15].

Regarding the size of reinforcing particles in composites, numerous studies have been examined. According to the report by Saini et al., the improvement in the properties of PVC composites in the presence of filler with small particle sizes was significant [16]. Based on the approach presented in another study, the particle size of CaCO3 is generally comparable to that of PVC particles, and for this reason it is capable of creating friction between the particles and PVC, increasing shear strength, and reinforcing gelation [17].

Aouat et al. [18] showed in their research that CaCO3 can act as a fusion promoter. According to their report, one of the possible reasons for the observed trend could be that coarser particles with a larger surface area have greater contact with PVC particles, which generates more shear heat and increases the fusion rate. CaCO3 is usually surface-treated with stearic acid, producing a layer of calcium stearate on the filler surface. This leads to improved processing and dispersion, and the mechanical properties increase. In another work, they investigated the effect of fiber diameter and loading on the mechanical properties of polyvinyl chloride composites reinforced with date palm trees, and reported that this can be related to fiber geometry, since it may affect the transfer of the applied load stress to the composites, which occurs through shear at both the interfaces along the fiber and at the fiber ends. Fiber size affects the flexural strength of PVC composites. According to the results obtained, unsieved composites possess greater flexural strength, which increased for fiber lengths from 125 to 500 micrometers and then decreased. Fibers smaller than 125 micrometers

present in unsieved composites may be able to fill the voids around larger fiber sizes and make the composites more compact.

Hamour et al. investigated the effect of alfa fiber particle size on the mechanical properties of composites containing PVC. The presence of small particle sizes showed a beneficial effect on the mechanical properties due to the qualitatively improved adhesion between the polymer and the fiber [19]. The composite's characteristics depend on the quality of the fiber-matrix interface, which embodies the concept of adhesion. The bonds formed at the interface between the fibers and polymers determine the physico-mechanical properties of composite materials. The improved quality of matrix adhesion to the fibers is usually achieved through physical activations, compatibilizers, which in some cases have reacted on the fiber or have been precipitated in the polymer [20].

Aouat et al. incorporated wheat husk as a reinforcing filler into the PVC matrix, and to improve interfacial adhesion, the fiber surface was chemically treated with acrylic acid (AA). According to the results obtained, the combination of fibers with increasing fiber loading increased the modulus justifiably; however, there was weak physical bonding between the filler and the matrix, which hindered uniform stress distribution and led to a reduction in tensile strength. However, the chemical treatment creates better surface adhesion between the fibers and the matrix and causes an improvement in the mechanical properties of the composites [21]. The reinforcement decreases when the adhesion between the fiber and the matrix is low. The treatment of fibers and some additives used in the composite, with tensile correction at the interface, guarantees the improvement of these materials' properties. As reported by Tawiah et al. [22], an improvement in tensile strength was observed between PVC composites and olive husk flour reinforced with benzoyl peroxide and PVC-g-MA in comparison with unreinforced composite, which may be due to better dispersion of the filler and better adhesion between PVC and olive husk flour.

Hammiche et al. [23] also investigated the effects of PVC-g-MA as a compatibilizer on the mechanical properties of PVC/alfa. When the composite is modified with coupling agents, a broader and more progressive improvement in tensile strength occurs. The coupling agent improves the mechanical strength of the materials using a chemical mechanism. This mechanism is based on the formation of ester bonds between the -OH groups of the alfa fibers and the functionalization of maleic anhydride in PVC-g-MA, and as a result, it creates chemical anchoring of the polymer matrix on the fiber surface. The results obtained by Hammiche et al. [24] in another investigation show that the tensile strength of composites decreases with increasing fiber content due to weak surface adhesion and low compatibility between alfa fibers and PVC, which leads to an increase in the voids between the fibers and the matrix, weakening the fiber-matrix interfacial adhesion. However, the tensile resistance of the composites after the addition of 3 wt% PVC-g-MA was significantly greater than that of unreinforced composites due to the increase in interfacial adhesion. Also, the adhesion between the fiber and the matrix strengthens the materials and increases the energy required to break them.

Boukerrou et al. argue that after studying the mechanical behavior of PVC-OHF composites, better behavior is exhibited by the reinforced composite materials. This improvement results from higher fiber-matrix interfacial adhesion. Fiber-reinforced crack allows for an increase in the strength of the materials, and the treatment makes it possible to achieve even higher mechanical properties in Young's modulus. In recent years, several publications have been released that document the

significant influence of the preparation process on the properties of PVC composites. Processing conditions, when carried out through a different preparation process, lead to different properties in the final product, and the appropriate process is identified according to the intended application [25]. Basbougà et al. also studied the influence of processing methods on the mechanical properties of PVC/wood flour composites, whereby higher tensile and flexural strength was obtained with the injection molding process compared to the compression molding process [26]. Based on the approach presented in PVC reinforced with wood and rice husk fiber, press molding is a two-stage process following the extrusion process. The comparison of the mechanical properties of the composites showed that the compression process is more effective than the twin-screw extrusion process, since the higher mechanical properties of PVC composites were obtained using the compression molding technique due to lower shear stress, less rice husk fiber breakage, and higher bulk density [27].

From the investigations that have been carried out, it can be concluded that PVC responds uniquely to practical additions, which makes it possible to produce both rigid and flexible products, which can be beneficial in engineered design applications. When fibers merely act as fillers, they contribute less to the improvement of mechanical resistance.

## 3. Manufacturing Process of Composites and Nanocomposites

In the composite manufacturing process, three common techniques are used: calendering, Brabender, and plastic injection, each having its own characteristics and specific applications. In the calendering method, the composite raw materials are placed between two or more moving heated rollers and, under pressure and heat, are transformed into thin sheets or composite plates with uniform thickness. This method is suitable for high-volume production and is mostly used in the packaging, automotive, and coatings industries. Brabender mixers have two screws (mixers). In this device, the raw materials are mixed under pressure, heat, and shear, which is used for producing composites on a laboratory scale. This method is very suitable for studying the rheological behavior and uniform mixing of the materials and is employed for mechanical test specimens and microstructural examination tests. In this method, precise control over the mixing conditions can be exercised. In the plastic injection method, the molten materials are injected into the mold and shaped under high pressure, and it is suitable for the production of composite parts with complex geometry and mass production, which is mostly applied in the automotive, medical equipment, and home appliance industries. Each of the aforementioned techniques, depending on the type of raw materials and the required properties in the final product, is selected to help produce composites with specific characteristics and optimal performance. A comparison between the manufacturing processes in PVC composites affects the mechanical properties of these composites [28]. According to the report by Koubaa et al. [29], the tensile modulus and flexural modulus of composites produced by the injection molding method were higher than those prepared by the extrusion method. They showed that the differences in mechanical behavior, depending on the processing method, can only partially explain the behavior of the fibers in the composite structure. The extrusion process is usually accompanied by fiber breakage, particularly in the case of loaded fibers. It is possible that mixing and injection molding processes result in less fiber breakage than the extrusion process. The aforementioned investigations have been conducted on this parameter.

Hammiche et al. [30] developed PVC-alfa composites using three techniques: rolling, Brabender, and injection molding. The comparative study showed that the mechanical properties of PVC and its composites differ. In the case of PVC, the tensile strength and Young's modulus in the two-roll rolling state were higher than in Brabender and injection molding, which is why rolling is considered the best technique for preparing PVC. It is also interesting that the best performances regarding the composites were related to those prepared by the injection molding method. In fact, the composites obtained through injection molding exhibited the highest tensile strength and Young's modulus. As is known, the Young's modulus increases due to the dependence of its strength on the proper distribution of fibers in the matrix, and fiber aggregation leads to insufficient homogeneity of the composite and acts as crack initiation points under load. The appearance and intensity of fiber aggregation depend on the forces that have attracted the fibers to one another and tend to separate them. The hydrogen bonds responsible for the interaction and engagement of the fibers are sufficiently strong.

## 4. Mechanical Properties of PVC Nanocomposites

Nanocomposites have captured the global market because of their excellent mechanical properties, light weight, good modulus and improved dimensional stability, as well as better scratch and impact resistance. These features have enabled this type of nanocomposite to become a suitable substitute in high-consumption automotive components. Recent estimates indicate that nanomaterials accounted for 73% of the nanotechnology market in 2015. This share reached 82% in 2019 [31].

In nanocomposites, the reinforcement has at least one dimension in the nanometer scale, usually less than 100 nm. Nanocomposites are also widely used; the addition of nanoreinforcements can achieve significant improvements in nanocomposite properties, mainly mechanical properties [32–35], because these reinforcements have a high specific surface area and increase the interfacial contact area between components, improving the surface-to-volume ratio. These changes lead to improvement and strengthening of the overall performance of the materials and enhance their capabilities.

Compared with conventional microfillers, the addition of a very small amount of nanoclay can result in excellent property development without a significant increase in density or a loss of light-transmission properties in the PVC base polymer [36]. In another study, nanosilica was used to increase the mechanical properties of PVC [37]. The addition of graphene content to PVC increases the strength of nanocomposites because of good dispersion. Carbon improves the adhesion between the polymer and fibers, and then the matrix phase is reinforced, resulting in increased compressive strength and elastic modulus [38]. In one report [39], graphite was used as a flame retardant, and graphene oxide (GO) improved the mechanical properties of PVC nanocomposite films [40].

In addition to these, hybrid composites are also used and can result in high mechanical properties. In fact, the combination of PVC/glass-fiber/graphene composites increases the mechanical strength of the composites produced, because carbon nanotubes can improve interfacial adhesion. According to Kiersnowski et al. [41], the processing conditions of polymer nanocomposites with a low filler percentage are similar to those of pure resins, and the usual processing problems of microcomposites are not observed in these cases. Given the nanometer dimensions of clay particles, which are close to molecular dimensions, a large interphase surface is obtained at low filler percentages. This feature means that even a small amount of filler can have a considerable effect on the initial polymer matrix.

Although PVC is one of the principal thermoplastic polymers, PVC-clay nanocomposites are still at a preliminary stage [42]. Sultana et al. [43] produced PVC-matrix nanocomposites with different combinations of pyrol and barium hexaferrite using the solution-casting method, to a thickness of 0.5 mm. With the addition of 2.5 wt% barium hexaferrite, the highest elongation and strength were obtained because of complete dispersion and strong interaction of the fillers with the PVC matrix. However, when the barium hexaferrite content was increased to 5 wt%, a decrease in properties was observed owing to partial agglomeration of fillers in the matrix.

The effect of the amount of titanium dioxide nanoparticles on the mechanical properties of PVC composites was investigated by Ngat et al. [44]. To achieve optimal dispersion and increase compatibility between the nanoparticles and PVC, the titanium dioxide surface was modified using vinyl silane and amino silane. Vinyl silane showed a better improvement in mechanical properties than amino silane, particularly at high nanoparticle weight percentages. The reason for this is the improvement in the PVC–titanium dioxide interphase due to the similarity in polarity and surface tension values of vinyl silane with the PVC matrix and nanoparticles. According to Leszczynska et al. [45], when nanoparticles are properly modified and dispersed in a polymer matrix, effective interactions between the organic and mineral phases of the composite are created, which can lead to synergistic effects.

Organic nanofillers are also widely used in nanocomposite materials. Nanocellulose, because of its high stiffness and strength, can enhance the mechanical properties of nanocomposites. The principal reason for using nanocellulose as reinforcement in a polymer matrix is to exploit the high stiffness of crystalline cellulose. According to the method presented in reference [46], PVC was reinforced with different weight percentages of nanocellulose (2, 4, 6, 8, and 10%), and the nanocomposites were prepared using solution casting. The tensile strength of the nanocomposites decreased as the nanocellulose content increased, and the highest value was obtained for nanocomposites reinforced with 2 wt% nanocellulose.

The use of nanocellulose as reinforcement in a PVC matrix was also investigated by Hammiche et al. [47, 48]. Nanocellulose was prepared from alfa fibers using an alkaline process at room temperature together with a bleaching process, followed by hydrolysis with sulfuric acid. The properties of nanocellulose-based nanocomposites were compared using two different methods: dispersing nanocellulose in clay and dispersing it in polyethylene glycol (PEG). The results showed that the dispersion method and the organization of reinforcements play a key role in nanocomposite properties. The Cloisite 30B/CNW system showed greater organization and a greater improvement in properties. Dispersion in clay improved the Young's modulus, whereas the presence of PEG, due to its plasticizing effect, led to a reduction in this property.

Prabu et al. [49] produced hybrid nanocomposites containing a fixed amount of carbon black and varying amounts of halloysite nanotubes by melt mixing and using a two-roll mill. The tensile strength, elongation at break, and modulus of the hybrid nanocomposites increased by 12.87%, 13.91%, and 23.22%, respectively, using 4 carbon black per 100 parts of PVC matrix. According to the authors, the synergistic effect of hybrid fillers, enhanced interphase interactions, and the formation of interwoven structures lead to improved mechanical properties of nanocomposites.

In a study conducted by Abbas et al. [50], PVC polymer composites were loaded with micro- and nano-sized PbO/CuO particles. At the same filler content, composites containing nanoparticles exhibited better mechanical properties than composites based on bulk fillers. This was attributed to

the uniform dispersion of nanoparticles in the PVC matrix. Therefore, at the same particle content, nanofillers are more efficient in reinforcing the polymer matrix and improve mechanical properties to a greater extent; in other words, smaller particles provide better reinforcement.

Yazdani et al. [51] investigated the effect of processing conditions on the mechanical properties of PVC composites filled with carbon nanotubes using four different dispersion methods: probe ultrasonication, bath ultrasonication, mechanical stirring, and batch mixing. The mechanical properties of the composite were considered an indicator of filler-dispersion quality in the composite. The findings showed a direct relationship between dispersion quality and the mechanical properties of composite samples. Samples well dispersed using probe ultrasonication showed greater tensile strength and elongation at break.

Sterky et al. [52] compared the effects of processing techniques on the mechanical properties of montmorillonite-reinforced PVC using a two-roll mill or a microcompounder. It was found that the processing technique used affects the extent of dispersion and exfoliation of the clay and consequently the resulting mechanical properties. Elongation at break and impact resistance were better in the milled samples. However, the modulus and tensile strength were considerably higher in the microcomposite samples, despite their larger particle size. This was attributed to the higher degree of orientation in these samples.

## 5. Conclusion

The use of nanofillers in a polymer matrix, owing to their high specific surface area, increases the interfacial contact area between components, leading to improvement and strengthening of the overall product performance and enhanced material capabilities. Extensive studies show that the mechanical properties of composites and nanocomposites—including tensile and flexural strength, Young's modulus, and elongation at break—are influenced by numerous factors, including:

- Composite processing and manufacturing conditions: The manufacturing technique should be selected according to the raw materials and required properties, favoring conditions that result in lower shear stress and less fiber breakage.
- Type of additive: Compatibility and effective interactions can affect the interfacial behavior of the PVC matrix with nanoparticles.
- Surface-modification mechanisms: Chemical treatment and physical activation, aided by surface modifiers and compatibilizers, can form bonds at the interface between fibers and polymers, promote interphase interactions, and form interwoven structures.
- Size of reinforcing particles: A high specific surface area increases interfacial contact between components and strengthens polymer-fiber interfacial adhesion.
- Appropriate amount and content of filler particles in the matrix: Proper mixing of fibers and avoidance of nonuniformity help prevent stress concentration and the deterioration of mechanical properties.
- Uniform distribution and dispersion of fibers in the matrix: Various dispersion techniques can distribute fibers uniformly in the matrix and prevent fiber agglomeration, which can act as crack-initiation sites under loading.

***Table 1.*** Abbreviations

| Abbreviation | Full term |
|---|---|
| PMC | Polymer matrix composites |
| MMC | Metal matrix composites |
| CMC | Ceramic matrix composites |
| PVC | Polyvinyl chloride |
| PE | Polyethylene |
| PP | Polypropylene |
| GO | Graphene oxide |
| PEG | Polyethylene glycol |
| AA | Acetic anhydride |

## References

[1] Mercier, J. P., Ambelli, G. Z., & Kurz, W. (2002). Introduction à la science des matériaux (3rd ed.). Lavoisier.

[2] Vilay, V., Mariatti, M., Mat Taib, R., & Todo, M. (2008). Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber-reinforced unsaturated polyester composites. Composites Science and Technology, 68(3–4), 631–638.

[3] Zarate, C. N., Aranguren, M. I., & Reboredo, M. M. (2008). Thermal degradation of a phenolic resin, vegetable fibers, and derived composites. Journal of Applied Polymer Science, 107(5), 2977–2985.

[4] Zhou, Y., Pervin, F., Rangari, V. K., & Jeelani, S. (2006). Fabrication and evaluation of carbon nanofiber filled carbon/epoxy composite. Materials Science and Engineering: A, 426(1–2), 221–228.

[5] Setua, D. K., & De, S. K. (1984). Short silk fibre reinforced nitrile rubber composites. Journal of Materials Science, 19(3), 983–999.

[6] Lu, W., Lin, H., & Chen, G. (2007). Voltage-induced resistivity relaxation in a high-density polyethylene/graphite nanosheet composite. Journal of Polymer Science, Part B: Polymer Physics, 45(7), 860–863.

[7] Rezaei, F., Yunus, R., Ibrahim, N. A., & Mahdi, E. S. (2008). Development of short-carbon-fiber reinforced polypropylene composite for car bonnet. Polymer-Plastics Technology and Engineering, 47(4), 351–357.

[8] Chazeau, L., Cavaille, J. Y., Canova, G., Dendievel, R., & Boutherin, B. (1999). Viscoelastic properties of plasticized PVC reinforced with cellulose whiskers. Journal of Applied Polymer Science, 71(11), 1797–1808.

[9] Chen, J., & Tsubokawa, N. (2000). Electric properties of conducting composite from poly(ethylene oxide) and poly(ethylene oxide)-grafted carbon black in solvent vapor. Polymer Journal, 32(9), 729–736.

[10] Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). A review on the tensile properties of natural fibre reinforced polymer composites. Composites Part B: Engineering, 42, 856–873.

[11] Rocha, N., Kazlauciunas, A., Gil, M. H., Gonçalves, P. M., & Guthrie, J. T. (2009). Poly(vinyl chloride)–wood flour press mould composites: The influence of raw materials on performance properties. Composites Part A, 40, 653–661.
[12] Bledzki, A. K., Reihmane, S., & Gassan, J. (1998). Thermoplastics reinforced with wood fillers: A literature review. Polymer-Plastics Technology and Engineering, 37, 451–468.
[13] Jiang, H., & Kamdem, D. P. (2002). Development of poly(vinyl chloride)/wood composites: A literature review. Journal of Vinyl and Additive Technology, 10, 59–69.
[14] Laurent, M., Matuan, M., Chul, B., Park, J., & Balatinecz, J. (1997). The effect of low levels of plasticizer on the rheological and mechanical properties of polyvinyl chloride/newsprint-fiber composites. Journal of Vinyl and Additive Technology, 3, 266–273.
[15] Ahmad, I., Baharum, A., & Abdullah, I. (2006). Effect of extrusion rate and fiber loading on mechanical properties of Twaron fiber-thermoplastic natural rubber (TPNR) composites. Journal of Reinforced Plastics and Composites, 25, 957–965.
[16] Saini, G., Bhardwaj, R., Choudhary, V., & Narula, A. K. (2010). Poly(vinyl chloride)–Acacia bark flour composite: Effect of particle size and filler content on mechanical, thermal, and morphological characteristics. Journal of Applied Polymer Science, 117, 1309.
[17] Jemii, H., Hammiche, D., Boubakri, A., Haddar, N., & Guermazi, N. (2020). Mechanical, thermal and physico-chemical behavior of virgin and hydrothermally aged polymeric pipes. Journal of Thermoplastic Composite Materials, 1–21.
[18] Awad, S., Hamouda, T., Midani, M., Zhou, Y., Katsou, E., & Fan, M. (2021). Date palm fibre geometry and its effect on the physical and mechanical properties of recycled polyvinyl chloride composite. Industrial Crops and Products, 174, 114172.
[19] Boukerrou, A., Hamour, N., Djidjelli, H., & Hammiche, D. (2012). Effect of the different sizes of the alfa on the physical, morphological and mechanical properties of PVC/Alfa composites. Macromolecular Symposia, 321–322, 191–196.
[20] Gasson, J., & Bledzki, A. K. (2000). Possibilities to improve the properties of natural fiber reinforced plastics by fiber modification—jute polypropylene composites. Applied Composite Materials, 7, 373–385.
[21] Aouat, H., Hammiche, D., & Boukerrou, A. (2021). On the mechanical properties of composites based on wheat husk and polyvinyl chloride. Macromolecular Symposia, 395, 2000248.
[22] Aouat, H., Hammiche, D., Boukerrou, A., Djidjelli, H., Grohens, Y., & Pillin, I. (2021). Effects of interface modification on composites based on olive husk flour. Materials Today: Proceedings, 36, 94–100.
[23] Hammiche, D., Boukerrou, A., Djidjelli, H., & Djerrada, A. (2013). Effects of some PVC-grafted maleic anhydrides (PVC-g-MAs) on the morphology, and the mechanical and thermal properties of (Alfa fiber)-reinforced PVC composites. Journal of Vinyl and Additive Technology, 19, 225–232.
[24] Hammiche, D., Boukerrou, A., Djidjelli, H., Beztout, M., & Krim, S. (2012). Synthesis of a new compatibilisant agent PVC-g-MA and its use in the PVC/alfa composites. Journal of Applied Polymer Science, 124, 4352–4361.
[25] Boukerrou, A., Hammiche, D., Djidjelli, H., & Aouat, H. (2014). Physical and mechanical properties of polymer composite materials based on olive husk flour. Journal of Renewable Materials, 2.
[26] Başboğa, I. H., Karakuş, K., Atar, I., Bozkurt, F., & Mengeloğlu, F. (2017). Effects of processing methods, dioctyl phthalate (DOP) amount and filler content on the mechanical properties of recycled polyvinyl chloride (PVC) composites. Journal of King Saud University–Engineering Sciences, 20, 9–15.
[27] Migneault, S., Koubaa, A., Erchiqui, F., Chaala, A., Englund, K., & Wolcott, M. P. (2009). Effects of processing method and fiber size on the structure and properties of wood–plastic composites. Composites Part A, 40, 80–85.

[28] Hammiche, D., Boukerrou, A., Duchet-Rumeau, J., & Gerard, J. F. (2021). Correlation between composites behavior and the manufacturing process used. Macromolecular Symposia, 395, 2000248.
[29] Sultana, S., Mahbub Reja, M., Naher Hilary, L., Saiful Islam, M., Zamsed Uddin, M., & Walliullah, M. (2021). Preparation and characterization of nanocellulose from Albizia lebbeck sawdust and their application in nanocomposites using poly(vinyl chloride) (PVC). Journal of Polymers and the Environment.
[30] Zhang, J., Manias, E., & Wilkie, C. A. (2008). Polymerically modified layered silicates: An effective route to nanocomposites. Journal of Nanoscience and Nanotechnology, 8, 1597–1615.
[31] Grand View Research. (2015, September). Global nanocomposites market analysis by product (carbon nanotubes, nanoclay, metal/metal oxides, ceramics, others), by application (packaging, automotive, electronics & electrical, aviation, energy, construction, military, others) and segment forecasts to 2022.
[32] Frounchi, M., Dadbin, S., Salehpour, Z., & Noferesti, M. (2006). Gas barrier properties of PP/EPDM blend nanocomposites. Journal of Membrane Science, 282, 142–148.
[33] Shabani, I., Haddadi-Asl, V., Seyedjafari, E., & Soleimani, M. (2012). Cellular infiltration on nanofibrous scaffolds using a modified electrospinning technique. Biochemical and Biophysical Research Communications, 423, 50–54.
[34] Zare, Y., & Garmabi, H. (2012). Analysis of tensile modulus of PP/nanoclay/$CaCO_3$ ternary nanocomposite using composite theories. Journal of Applied Polymer Science, 123, 2309–2319.
[35] Zare, Y., Garmabi, H., & Sharif, F. (2011). Optimization of mechanical properties of PP/nanoclay/$CaCO_3$ ternary nanocomposite using response surface methodology. Journal of Applied Polymer Science, 122, 3188–3200.
[36] Zhang, J., Manias, E., & Wilkie, C. A. (2008). Polymerically modified layered silicates: An effective route to nanocomposites. Journal of Nanoscience and Nanotechnology, 8, 1597–1615.
[37] Sun, S., Li, C., Zhang, L., Du, H., & Burnell-Gray, J. S. (2006). Effects of surface modification of fumed silica on interfacial structures and mechanical properties of poly(vinyl chloride) composites. European Polymer Journal, 42, 1643–1652.
[38] Shanmugasundar, G., Vanitha, M., Ganesh Babu, L., Suresh, P., Mathiyalagan, P., Sai Krishnan, G., & Makos, M. (2020). Fabrication and analysis of mechanical properties of PVC/glass fiber/graphene nano composite pipes. Materials Research Express, 7, 11530.
[39] Focke, W. W., Muiambo, H., Mhike, W., Kruger, H. J., & Ofosu, O. (2014). Flexible PVC flame retarded with expandable graphite. Polymer Degradation and Stability, 100, 3–69.
[40] Deshmukh, K., & Joshi, G. M. (2014). Thermo-mechanical properties of poly(vinyl chloride)/graphene oxide as high-performance nanocomposites. Polymer Testing, 34, 211–219.
[41] Kiersnowski, A., Trelińska-Wlazlak, M., Gazińska, M., & Pigłowski, J. (2011). X-ray scattering and calorimetric studies of organoclays obtained by ion-exchange. Polimery, 56, 671–675.
[42] Hasegawa, N., Okamoto, H., Kato, M., Usuki, A., & Sato, N. (2003). Nylon 6/Na–montmorillonite nanocomposites prepared by compounding Nylon 6 with Na–montmorillonite slurry. Polymer, 44, 2933–2937.
[43] Sabahat, S., Muhammad, Z., Rukhsar, A., Fayzan, H. M. S., & Rehan, Z. A. (2021). Fabrication and characterization of PVC based flexible nanocomposites for the shielding against EMI, NIR, and thermal imaging signals. Results in Physics, 24, 104183.
[44] Abdel-Gawad, N. M. K., Adel, M., Diaa-Eldin, A. M., Hanaa, M., Darwish, M. M. F., & Lehtonen, M. (2020). PVC nanocomposites for cable insulation with enhanced dielectric properties, partial discharge resistance and mechanical performance. High Voltage, 5, 463–471.

[45] Leszczynska, A., Njuguna, J., Pielichowski, K., & Banerjee, J. R. (2007). Polymer/montmorillonite nanocomposites with improved thermal properties, Part II: Thermal stability of montmorillonite nanocomposites based on different polymeric matrixes. Thermochimica Acta, 454, 1–22.

[46] Abdul Khalil, H. P. S., Bhat, A. H., & Ireana Yusra, A. F. (2012). Green composites from sustainable cellulose nanofibrils: A review. Carbohydrate Polymers, 87, 963–979.

[47] Hammiche, D., & Boukerrou, A. (2014). Performances of composites based on alfa fiber, Stipa tenacissima. In R. Kumar (Ed.), Polymer-matrix composites: Type, applications and performance (pp. 109–128). Nova Science Publishers.

[48] Hammiche, D., Boukerrou, A., Djidjelli, H., Grohens, Y., Bendahou, A., & Seantier, B. (2016). Characterization of cellulose nanowhiskers extracted from alfa fiber and the effect of their dispersion methods on nanocomposite properties. Journal of Adhesion Science and Technology, 30, 1899–1912.

[49] Prabu, B., & Senthilvel, K. (2018). Studies on the mechanical properties of carbon black–halloysite nanotube hybrid fillers in nitrile/PVC nanocomposites for oil seal applications. Journal of Scientific Research in Physics and Applied Sciences, 6, 63–68.

[50] Abbas, Y., El-khatib, A. M., Badawi, M. S., Alabsy, M. T., & Hagag, O. M. (2021). Gamma attenuation through nano lead—nano copper PVC composites. Nuclear Technology and Radiation Protection, 36, 50–59.

[51] Yazdani, H., Smith, B. E., & Hatami, K. (2016). Multi-walled carbon nanotube-filled polyvinyl chloride composites: Influence of processing method on dispersion quality, electrical conductivity and mechanical properties. Composites Part A: Applied Science and Manufacturing, 82, 65–77.

[52] Sterky, K., Jacobsen, H., Jakubowicz, I., Yarahmadi, N., & Hjertberg, T. (2010). Influence of processing technique on morphology and mechanical properties of PVC nanocomposites. European Polymer Journal, 46, 1203–1209.