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TRENDS ON REINFORCED POLYMER COMPOSITES – A REVIEW

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ABSTRACT

In recent years, the interest in using fiber reinforced composites (FRC) has increased due to their potential to replace traditional materials in various applications. The advantages of polymer composites from natural fibres are: biodegradability, high performance, market availability and low price. This article is based on a review that discusses both polymer composite materials and typical applications by other authors on fiber reinforced composites (FRCs).

KEYWORDS: polymer, fibres, composites

1. Introduction

The development of composite materials plays a crucial role in the advancement of technology [1-5]. Considering that both industrial and technological requirements are continuously increasing in fields (energy, naval, aerospace and automotive), there is a need for devices based on high-performance materials that can perform more than one function. This frequently involves the ability to respond in a controllable way to a certain physical or chemical stimulus, changing at least one of the material properties in direct correlation with the external stimulus [6].

Fiber reinforced composite materials are used in various industries due to their mechanical strength, modulus and corrosion resistance. Polymer nanocomposites based on carbon nanostructures for strain and temperature self-sensing have been proposed as the next generation of materials that are expected to overcome the well-known problems of inorganic sensors, such as complex processing, brittleness, narrow sensing range, and high sensitivity [7-10]. The polymer blend is the addition of two polymers at the macromolecular level, and the phase-separated morphology will influence the mechanical performance of the blend. Due to the poor reactivity of polymer-based materials with modifiers, poor adhesion between the epoxy and the modifier can result, and that can lead to a reduction in the mechanical properties of the composite. Therefore, the characterization of polymer matrix composites is essential [11].

For the synthesis of polymer-based composites there are, at least, two processes that are governing the formation of polymers and associated composites: direct processing and in situ preparation. The direct mixing method involves synthesizing the desired nanomaterial and then dispersing it into the polymer matrix either by solution or mechanical dispersion. In the case of preparing composites based on in situ polymerization, the polymeric material creates a microenvironment to produce the desired metal/metal oxide from the precursors through series of chemical reactions. This process is of particular interest because the particle size and morphology could be easily controlled [12]. Analysing current trends, it can be seen that fiber reinforced thermosetting composites are among the most important materials. Due to the reliable mechanical performance of fiber reinforced polymer (FRP) composites, they have gained a huge market opening with inherent properties such as high corrosion resistance, high strength and improved fatigue resistance. These properties are superior because they are based on the interfacial bonds and cross-links between the matrix and the fiber. Thermosetting matrices such as epoxy, vinyl ester and polyester are commonly used as polymer matrices. Among them, epoxy resin is commercialized as a structural adhesive and as a polymer matrix for FRP composites [13]. Modification of epoxy resin (EP) with nanofillers has been extensively explored over the past three decades. Nanomaterials including carbon nanotubes, nanofibers (VGCF), organoclay, graphene oxide (GO) and its derivatives, functionalized aramid nanofibers (fANF) have been used in EP modification [14].

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2. Kevlar fibres

Due to its unique properties, Kevlar fiber has become very popular as reinforcing material in composite materials, and its applications are considerably increasing [15-17]. Composite materials reinforced with synthetic fibres have become significantly popular over the years [18-20]. Among the synthetic fibres, poly-aramid fibres known as Kevlar fibres are mainly used for applications in industrial and advanced technologies such as ballistic armour, helicopter blades, pneumatic fittings, sports goods [21-23]. Their application has become considerably very wide due to its excellent mechanical properties, lighter weight, unique flexibility, corrosion resistance, ease of manufacture, etc. [24-26]. Compared with other synthetic fibres, Kevlar fiber has an elongation of fibres significantly lower and higher tensile strength and modulus [27]. They also exhibit very good properties at high temperatures for a polymeric material [28-30]. The glass transition temperature of Kevlar fiber is around 360 °C and it does not melt like nylon [31-33].

3. Polymer matrix composites (PMCs)

PMCs are promising materials for many engineering applications due to their superior properties such as self-lubricating properties, excellent chemical stability, electrical insulation properties, and wear resistance [34-37]. They have applicability in the aerospace, marine and sports industries. Also, other applications include the toy industry, coal handling equipment in power plants, bearings, transmission pumps, cosmetics and medical devices [38-42]. The advantages of polymer composites from natural fibres are: biodegradability, high performance, availability on the market and low price [43-48]. Hybrid composite is the material made from natural fibres and carbon fibres [49-51]. Interest in fabric-reinforced thermoplastic matrix composites has increased in recent years due to their faster processing possibilities compared to traditional thermo-resistant matrix composites [52, 53]. Textiles pre-impregnated with thermoplastic resins can be heated above the melting point of the matrix in seconds using infrared heaters and can be formed into a three-dimensional (3D) component [54-62], which involves significantly longer cycle times shorter than autoclave processing or resin transfer techniques [63-72]. Advanced fabrication techniques such as local reinforcement by tape placement is also facilitated due to the presence of the thermoplastic matrix [34]. Improved performance, shorter cycle times and reduced density are some features that have made woven thermoplastic composites attractive for the aerospace and automotive industries [73-76]. Polymer matrix composites can be fabricated by various methods such as liquid casting, compression moulding, resin injection, and injection moulding, all of which belong to autoclave manufacturing methods [77-79]. In the field of external strengthening and repair of existing structures made of traditional materials such as concrete and masonry, fiber reinforced polymer (FRP) [80-84], has attracted much attention worldwide due to its ease of application, ability to limit impact aesthetic of repair works to the original structure and its appropriate reversibility for historical or artistic reasons [85-89]. Currently, almost all FRP applications [90-92], involve FRP made with glass fiber (GFRP) [93-96], carbon fiber (CFRP) [97-102], and in a smaller measure aramid fiber (AFRP) [103-117].

4. Epoxy resin

There are different types of epoxy resins, such as bisphenol A diglycidyl ether, cycloaliphatic epoxy resins, trifunctional epoxy resins, and tetrafunctional epoxy resins [118]. The global commercialization of epoxy resins market reached USD 25.8 billion in 2018, and for the year 2022 it is estimated to be around USD 34 billion [119]. Among these, bisphenol A diglycidyl ether is the most widely used in the coating industry due to its low cost and many desirable properties such as hardness, gloss and chemical resistance. Epoxy resin is one of the most common thermoset resins widely used as composite matrix and high-performance coatings due to its excellent characteristics such as: mechanical strength, chemical resistance, low shrinkage and electrical insulating properties [120-122]. Since the 1950s, various reports have appeared in the literature detailing the complex internal nanostructure of epoxy resin [123]. One of the disadvantages of epoxy resin is the brittleness caused by the tight three-dimensional (3D) polymer network. In recent years, efforts have been made to solve the problem of fragility. The hardness of epoxy can be improved by using elastomers, thermoplastic materials, nanofillers [124]. The most common component of epoxy resins is diglycidyl ether bisphenol A (DGEBA). DGEBA is industrially synthesized by reacting bisphenol A (BPA) with a large excess of epichlorohydrin under alkaline conditions [125]. The behavior of the resin depends on certain factors such as time, temperature, curing speed and pressure on the curing process. Characterization of the cure-dependent thermo-mechanical behavior of a fast-curing resin under process-relevant conditions remains a challenge [126-128]. It is known that when properly cured, epoxy resins exhibit a high crosslink density. When used as matrices in polymer composites, brittle resins can produce composites with low damage tolerance [129-131]. Epoxy resins are frequently used as matrix of fiber reinforced composites. Matrix cracking has been shown to occur throughout the fracture process of the composite, particularly under fatigue loading. Brittleness of epoxy resins is the main source of composite failure, which can trigger composite defects such as delamination and debonding [132].

5. General presentation of the applications of composite materials

Cheng Chen *et al.* [133] performed a comparative analysis of natural fiber reinforced polymer and carbon fiber reinforced polymer for the strengthening of reinforced concrete beams. Due to the large amount of impregnated epoxy resin, the cost advantage of natural fibres was offset, and the overall cost efficiency of NFRP laminates ranged from 60% to 160% compared to CFRP laminates.

Sebastian Huayamares *et al.* [134] used unidirectional glass fiber reinforced epoxy, carbon fiber reinforced quasi-isotropic epoxy, and quasi-isotropic glass fiber reinforced epoxy to compare three-point bending and torsion methods to determine the viscoelastic properties of fiber-reinforced epoxy. This study showed that an irregular sample width can result in large dispersions in storage modulus values. Torsion tests, on the other hand, gave results that were consistent for fiber-reinforced composites regardless of specimen length, providing a more suitable method if materials are scarce and specimen length must be limited. Absolute values for viscoelastic properties cannot be directly compared between the three-point bending and torsion methods. At three-point bending, the storage and loss moduli were always higher than those measured in the torsional modulus for all of the studied composites.

This demonstrates that three-point bending measures higher moduli than torsion, regardless of fiber orientation, fiber type, or epoxy resin used for the two devices and test modes specified in this study.

Abdel-Hamid I. Mourad *et al.* [135] investigated the effect of nano additives on the damage resistance of a newly developed Kevlar fabric. Three types of nano additives were investigated: (1) silicon carbide (SiC), (2) aluminium oxide (Al_2O_3), and (3) carbon nanotubes. Damage was mainly observed in and around the impact area. The addition of small amounts of nano additives to Kevlar composites effectively improved the damage propagation resistance and interlaminar shear strength of the fabricated composites. In addition, increasing the nano additive content an improvement in the energy absorption capacity of the composites, especially with SiC and Al_2O_3 is observed, as the number of damaged layers and the percentage of damaged area decreases. Among all the samples examined, the lowest number of damaged layers with the smallest damaged area was obtained with the addition of 0.5% by mass.

Ali Tabatabaeian, and Ahmad Reza Santhosh G. and Rajath N. Rao [136] fabricated polymer hybrid composites based on thermosetting resins using different hybrid fibres/fabrics with and without castor oil. The effect of reinforcements and/or castor oil on mechanical and thermal behaviours were evaluated. The results showed that the tensile, flexural and impact strength of composites with castor oil increases compared to composites without castor oil. The thermal behaviour was evaluated using DMA, the results showed an increase in the damping properties of the composites with castor oil. Lower glass transition temperature for castor oil composites indicated better damping behavior at higher temperatures.

Bo Yang *et al.* [137] analysed the nesting effect on laminates. They found that compared to increasing the length of the main flow channel, decreasing the width is a more significant factor in reducing through-thickness permeability. The results also show that a considerable degree of Nesting can occur due to unidirectional displacement, the total thickness can decrease by up to 5-6%, and the through-thickness permeability reduction can reach up to 80%. Bidirectional fabric displacement leads to a greater degree of Nesting, the total thickness decreases by more than 12%, and the through-thickness permeability decreases by more than two orders of magnitude.

Dhanush Kumar *et al.* [138] analysed the tensile behavior of Kevlar and glass fiber reinforced hybrid polymer composite as a function of cut-out size and position. Based on the experimental results obtained after subjecting the Kevlar and fiberglass reinforced composites to tensile testing, the authors state that the strength of the plates was improved by making the holes further from the centre, where the load carrying capacity was higher and the concentration factor upon request it was smaller. The authors stated that by moving the holes away from the centre a higher load capacity is obtained. It was also observed that the strain hardening coefficient increases linearly from sample 1 to sample 5 indicating higher resistance to necking before fracture. This means that the boards can be stretched longer by moving the holes away from the centre.

Silvio Leonardo Valença *et al.* [139] evaluated the mechanical behavior of epoxy composite reinforced with plain Kevlar fabric and glass/Kevlar hybrid fabric. Thanks to the values obtained after the mechanical tests, it can be seen that the structures developed with Kevlar and glass fiber hybrid fabrics have transferred the highest values of mechanical strength and specific stiffness, becoming a new alternative for use as a structural laminated composite in the industrial market.

Xu W., *et al.* [140] performed experimental and analytical characterizations of finite interlaminar crack growth of 2D woven textile composites. The authors concluded that: the interlaminar static fracture resistance of the woven composite material determined by the double compliance method is consistent with that of the ASTM methods. The relative difference between the average fracture resistance obtained by these methods is less than 3%. The crack growth length can be accurately calculated using the dual compliance method, this advantage will significantly simplify the measurement of the strength at break of woven textile composites. The fracture strength of the unstable crack is given, in this paper, by using the dual compliance method. The fracture strength during unstable crack growth is lower than the initial fracture strength and results in the unstable growth of finite cracks.

Velmurugan V., *et al.* [141] performed an experimental evaluation of the mechanical properties of natural fiber reinforced polymer composites. The authors found that jute reinforcement with nylon fillers exhibits higher flexural strength compared to the combination of nylon and spider silk fillers in the flexural test. Reinforcement of the composite with spider silk and nylon fillers with epoxy matrix achieved higher toughness, and reinforcement with jute and nylon fillers with epoxy matrix achieved higher flexural and tensile strengths.

Murugan R., *et al.* [142] investigated the static and dynamic mechanical properties of glass epoxy composite fabrics and hybrid carbon composite laminates. Carbon laminate has higher mechanical strengths than glass laminate, except impact resistance. The variation in tensile strength and impact strength between the hybrid laminates is minimal, and the H2 hybrid layout has a higher flexural strength than the H1 hybrid laminate. The glass transition temperature, T_g of the H2 laminate has been changed by 5 °C to the glass laminate, which facilitates the higher operating temperature. The hybrid laminate with carbon fiber as the wrap layer, H2, performs better than another hybrid arrangement H1 and proves to be a good alternative for the glass laminate.

Jun Misumia and Toshiyuki Oyama [143] fabricated low-viscosity, high-strength epoxy resin modified by in situ radical polymerization method to improve the mechanical properties of carbon fiber reinforced plastics. In order to obtain both good mechanical properties, including the strength and toughness of the cured resin and the reduced viscosity of the uncured resin composition, the *radical in situ polymerization method* was applied to the epoxy resin for the CFRP matrix. The results demonstrated that the *in situ radical polymerization method* can be effective for improving the fracture strength of CFRP laminates while maintaining the low viscosity of the uncured resin composition.

Mawarnie Ismail, *et al.* [24] studied the mechanical properties of composites made by reinforcing epoxy resin with bidirectional glass fibres and short RH fibres. The total fiber content for each sample was 30% and 70% by mass for the epoxy resin. The mass distributions for the RH fiber were between 5%, 10% and 15% by mass, while 25%, 20% and 15% by mass for the bidirectional glass fiber. It was indicated that its mechanical properties tend to decrease when the RH fiber content exceeds 5% by mass.

Kiran M. D., *et al.* [144] evaluated the breaking strength of carbon fiber and epoxy composite with different carbon fiber thicknesses. The composites were fabricated using hand-stretching technique by infusing 200 gsm, 400 gsm resin and hybrid carbon fabric laminate. The fracture toughness of the hybrid carbon fiber composites was studied using the single-edge notched beam method at room temperature (25 °C). From the experimental results, it was found that the epoxy composites reinforced with 200 gsm carbon fiber resist at breaking better compared to the composites reinforced with other fibres.

Goli E., *et al.* [145] developed a homogenized thermochemical model to simulate the production of unidirectional composites made of carbon fibres embedded in a thermoset dicyclopentadiene (DCPD) matrix using frontal polymerization (FP). The reaction-diffusion model is then solved using the finite element method to investigate the temperature evolution and degree of hardening during the manufacturing process. The results reveal two different processing regimes: At lower fiber volume fractions, the polymerization front speed increases with fiber volume fraction due to the increase in the effective thermal conductivity of the composite. At higher fiber volume fractions, the frontal velocity decreases with increasing fiber content due to the reduced heat source generated by the exothermic reaction.

Dai S., *et al.* [146] fabricated six types of 3D woven composites from carbon fiber and epoxy matrix. They studied the influence of fiber architecture on the tensile, compressive and flexural behavior of 3D woven composites. Four orthogonal weaves and two blocking angles were tested with the primary loading direction parallel to the warp direction. The mechanical performance was found to be affected by the distribution of resin-rich regions and the waviness of the load-bearing fibres, which were determined by the fiber architectures. Bonding points in resin-rich regions were found to be the sites of damage initiation in all fabric types under all loading conditions, which was confirmed with both visual observation and image correlation strain maps.

In [147], the authors investigated a new epoxy resin matrix carbon fiber reinforced composite with viscoelastic sandwich layers by co-reinforcement technology. After testing, it was found that the addition of 0.1 mm thick damping film in laminates could lead to a 1.34% decrease in tensile strength and a 1.30% increase in flexural strength of the composites, reaching up to at 878.5 MPa and 766.3 MPa. However, the bending strength decreased with increasing thickness of the damping layer. The new co-reinforced damping composite exhibited high shear strength. The co-reinforced damping composites studied in this paper exhibited excellent damping properties.

In [148], the authors conducted a study that provides a low-cost solution to improve the mechanical and electrical properties of carbon fiber reinforced polymer composites by incorporating ultra-thin sheets of carbon nanotubes (CNTs) between CFRP layers (laminates). For this purpose, dry carbon fiber fabrics are first sandwiched between CNT sheets. The fabrics are then stacked and infused with epoxy to form a CFRP with interlaminated CNT sheets. Unlike the typical approach where micron-sized long CNTs are randomly distributed in a CFRP for reinforcement, this study uses 100nm-thick CNT sheets made of aligned and ultra-long (0.3 mm) nanotubes. Despite their negligible mass fraction of only 0.016%, interlaminar CNT sheets enhanced CFRP flexural strength by 49%, interlaminar shear strength by 30%, and mode I fracture strength by 30%. X-ray micro-tomography has shown that samples with interlaminar CNTs are significantly resistant to delamination and crack propagation. Moreover, the in-plane electrical conductivity of these composites increased proportionally with the mass fraction of CNTs, giving a maximum improvement of 278% over the reference sample for 0.048 mass% of CNT sheets.

6. Conclusions

- composite materials show a wide interest from researchers who approach a problem that starts from the matrix, reaches the reinforcement and the characterization of the materials;
- a lot of research considers composites with polymer matrix - either thermoset or thermoplastic;
- working models and interpretations of the results are proposed and, within certain limits, they are acceptable;
- many studies are carried out that take into account small variations of the matrix properties to identify the response of the composite;
- many studies refer to the matrix-reinforcement interphase (or other elements immersed in the polymer) to increase the utility value of the composites;
- we did not find bibliographic references regarding the analysis of the properties of polymer junctions, although in the design of the properties of composites a solution is to use layered matrices;
- some studies carried out at CCDCOMT aimed at the analysis of composites with a layered matrix consisting of the same polymer but modified in a different way for certain depths in the composite (the modifications being produced either by the introduction of solvents or by the addition of organic or inorganic agents).

References

[1]. Madra A., Breitkopf P., Raghavan B., Trochu F., *Diffuse manifold learning of the geometry of woven reinforcements in composites*, Comptes Rendus Mécanique, vol. 346, no. 7, p. 532-538, doi: 10.1016/j.crme.2018.04.008, iul. 2018.

[2]. Nair R. G., Sundararajan T., Guruprasad P. J., *A novel framework using point interpolation method with voxels for variational asymptotic method unit cell homogenization of woven composites*, Composite Structures, vol. 202, p. 261-274, doi: 10.1016/j.compstruct.2018.01.072, oct. 2018.

[3]. Vassilopoulos A. P., *The history of fiber-reinforced polymer composite laminate fatigue*, International Journal of Fatigue, vol. 134, p. 105512, doi: 10.1016/j.ijfatigue.2020.105512, mai 2020.

[4]. Kazemi M., Fini E. H., *State of the art in the application of functionalized waste polymers in the built environment*, Resources, Conservation and Recycling, vol. 177, p. 105967, doi: 10.1016/j.resconrec.2021.105967, feb. 2022.

[5]. Das P., Banerjee S., Das N. C., *Polymer-graphene composite in aerospace engineering*, în Polymer Nanocomposites Containing Graphene, Elsevier, p. 683-711, doi: 10.1016/B978-0-12-821639-2.00001-X, 2022.

[6]. Pech-Pisté R., Cen-Puc M., Balam A., May-Pat A., Avilés F., *Multifunctional sensing properties of polymer nanocomposites based on hybrid carbon nanostructures*, Materials Today Communications, vol. 25, p. 101472, doi: 10.1016/j.mtcomm.2020.101472, dec. 2020.

[7]. Shakil U. A., Abu Hassan S. B., Yahya M. Y., Nurhadiyanto D., *A review of properties and fabrication techniques of fiber reinforced polymer nanocomposites subjected to simulated accidental ballistic impact*, Thin-Walled Structures, vol. 158, p. 107150, doi: 10.1016/j.tws.2020.107150, ian. 2021.

[8]. Huang T., Gong Y., *A multiscale analysis for predicting the elastic properties of 3D woven composites containing void defects*, Composite Structures, vol. 185, p. 401-410, doi: 10.1016/j.compstruct.2017.11.046, feb. 2018.

[9]. Karmazin A., Kirillova E., Seemann W., Syromyatnikov P., *Investigation of Lamb elastic waves in anisotropic multilayered composites applying the Green's matrix*, Ultrasonics, vol. 51, no. 1, p. 17-28, doi: 10.1016/j.ultras.2010.05.003, ian. 2011.

[10]. Gupta P., *Polymer-graphene composites as sensing materials*, Polymer Nanocomposites Containing Graphene, Elsevier, p. 401-424, doi: 10.1016/B978-0-12-821639-2.00017-3, 2022.

[11]. Miah M. H., Chand D. S., Rahul B., Malhi G. S., *Mechanical behavior of unsaturated polyester toughened epoxy hybrid polymer network reinforced with glass fibre*, Materials Today: Proceedings, vol. 56, p. 669-674, doi: 10.1016/j.matpr.2022.01.069, 2022.

[12]. Yashas S. R., Shahmoradi B., Wantala K., Shivaraju H. P., *Potentiality of polymer nanocomposites for sustainable environmental applications: A review of recent advances*, Polymer, vol. 233, p. 124184, doi: 10.1016/j.polymer.2021.124184, oct. 2021.

[13]. Ganesh Gupta K. B. N. V. S., Hiremath M. M., Ray B. C., Prusty R. K., *Improved mechanical responses of GFRP composites with epoxy-vinyl ester interpenetrating polymer network*, Polymer Testing, vol. 93, p. 107008, doi: 10.1016/j.polymertesting.2020.107008, ian. 2021.

[14]. Wang W., Yu B., Zhang Y., Peng M., *Fully aminated rigid-rod aramid reinforced high strength epoxy resin and its composite with carbon fibers*, Composites Science and Technology, vol. 221, p. 109324, doi: 10.1016/j.compscitech.2022.109324, apr. 2022.

[15]. Bachchan A. A., Das P. P., Chaudhary V., *Effect of moisture absorption on the properties of natural fiber reinforced polymer composites: A review*, Materials Today: Proceedings, p. S2214785321019751, doi: 10.1016/j.matpr.2021.02.812, mar. 2021.

[16]. Zhou J., *et al.*, *Advanced functional Kevlar composite with excellent mechanical properties for thermal management and intelligent safeguarding*, Chemical Engineering Journal, vol. 428, p. 131878, doi: 10.1016/j.cej.2021.131878, ian. 2022.

[17]. Wu Y., *et al.*, *Liquid or solid? a biologically inspired concentrated suspension for protective coating*, Chemical Engineering Journal, vol. 428, p. 131793, doi: 10.1016/j.cej.2021.131793, ian. 2022.

[18]. Koohbor B., Ravindran S., Kidane A., *A multiscale experimental approach for correlating global and local deformation response in woven composites*, Composite Structures, vol. 194, p. 328-334, doi: 10.1016/j.compstruct.2018.04.016, iun. 2018.

[19]. Römelt P., Cunningham P. R., *A multi-scale finite element approach for modelling damage progression in woven composite structures*, Composite Structures, vol. 94, nr. 3, p. 977-986, doi: 10.1016/j.compstruct.2011.10.024, feb. 2012.

[20]. Jiang H., Ren Y., Gao B., Xiang J., *Numerical investigation on links between the stacking sequence and energy absorption characteristics of fabric and unidirectional composite sinusoidal plate*, Composite Structures, vol. 171, p. 382-402, doi: 10.1016/j.compstruct.2017.03.047, iul. 2017.

[21]. Saba N., Jawaid M., *Epoxy resin based hybrid polymer composites*, Hybrid Polymer Composite Materials, Elsevier, p. 57-82, doi: 10.1016/B978-0-08-100787-7.00003-2, 2017.

[22]. Madhavi P., Yadagiri G., Naveen A., Shravan M., Ravi A., Chandra Shekar K., *Flexural strength and inter laminar shear strength of carbon fabric and silk satin fabric reinforced hybrid composites*, Materials Today: Proceedings, vol. 19, p. 322-328, doi: 10.1016/j.matpr.2019.06.763, 2019.

[23]. Isart N., El Said B., Ivanov D. S., Hallett S. R., Mayugo J. A., Blanco N., *Internal geometric modelling of 3D woven composites: A comparison between different approaches*, Composite Structures, vol. 132, p. 1219-1230, doi: 10.1016/j.compstruct.2015.07.007, nov. 2015.

[24]. Ismail M., Rejab M. R. M., Siregar J. P., Mohamad Z., Quanjin M., Mohammed A. A., *Mechanical properties of hybrid glass fiber/rice husk reinforced polymer composite*, Materials Today: Proceedings, vol. 27, p. 1749-1755, doi: 10.1016/j.matpr.2020.03.660, 2020.

[25]. Shamohammadi Maryan M., Ebrahimnezhad-Khaljiri H., Eslami-Farsani R., *The experimental assessment of the various surface modifications on the tensile and fatigue behaviors of laminated aluminum/aramid fibers-epoxy composites*, International Journal of Fatigue, vol. 154, p. 106560, doi: 10.1016/j.ijfatigue.2021.106560, ian. 2022.

[26]. Louwsma J., Carvalho A., Lutz J.-F., Joly S., Chan-Seng D., *Adsorption of phenylalanine-rich sequence-defined oligomers onto Kevlar fibers for fiber-reinforced polyolefin composite materials*, Polymer, vol. 217, p. 123465, doi: 10.1016/j.polymer.2021.123465, mar. 2021.

[27]. Wang B., *et al.*, *Multiscale insights into the stretching behavior of Kevlar fiber*, Computational Materials Science, vol. 185, p. 109957, doi: 10.1016/j.commatsci.2020.109957, dec. 2020.

[28]. Li S., *et al.*, *Synthesis, processing and characterization of impact hardening gel (IHG) reinforced Kevlar fabric composites*, Materials & Design, vol. 195, p. 109039, doi: 10.1016/j.matdes.2020.109039, oct. 2020.

[29]. Chowdhury M. A., *et al.*, *Improvement of interfacial adhesion performance of the kevlar fiber mat by depositing $SiC/TiO_2/Al_2O_3$/graphene nanoparticles*, Arabian Journal of Chemistry, vol. 14, nr. 11, p. 103406, doi: 10.1016/j.arabjc.2021.103406, nov. 2021.

[30]. Lu W., Yu W., Zhang B., Dou X., Han X., Cai H., *Kevlar fibers reinforced straw wastes-polyethylene composites: Combining toughness, strength and self-extinguishing capabilities*, Composites Part B: Engineering, vol. 223, p. 109117, doi: 10.1016/j.compositesb.2021.109117, oct. 2021.

[31]. Singh T. J., Samanta S., *Characterization of Kevlar Fiber and Its Composites: A Review*, Materials Today: Proceedings, vol. 2, no. 4-5, p. 1381-1387, doi: 10.1016/j.matpr.2015.07.057, 2015.

[32]. Rana R. S., Buddi T., Purohit R., *Effect of SiC reinforcement on the mechanical properties of Kevlar fiber based hybrid epoxy composites*, Materials Today: Proceedings, vol. 44, p. 2478-2481, doi: 10.1016/j.matpr.2020.12.542, 2021.

[33]. Tilak S. R., Shuib Pasha S. A., Nayeem Ahmed M., Daniel S., *An experimental investigation of flexural and inter laminar shear stress on hybrid polymer based composites (E glass fibre – Kevlar fibre with Epoxy resin 5052) for different thickness*, Materials Today: Proceedings, vol. 46, p. 8991-8994, doi: 10.1016/j.matpr.2021.05.375, 2021.

[34]. Garoz D., Gilabert F. A., Sevenois R. D. B., Spronk S. W. F., Van Paepegem W., *Consistent application of periodic boundary conditions in implicit and explicit finite element simulations of damage in composites*, Composites Part B: Engineering, vol. 168, p. 254-266, doi: 10.1016/j.compositesb.2018.12.023, iul. 2019.

[35]. Vedrtnam A., Pawar S. J., *Laminated plate theories and fracture of laminated glass plate – A review*, Engineering Fracture Mechanics, vol. 186, p. 316-330, doi: 10.1016/j.engfracmech.2017.10.020, dec. 2017.

[36]. Obert E., Daghia F., Ladevèze P., Ballere L., *Micro and meso modeling of woven composites: Transverse cracking kinetics and homogenization*, Composite Structures, vol. 117, p. 212-221, doi: 10.1016/j.compstruct.2014.06.035, nov. 2014.

[37]. Prabhakar M. N., Naga Kumar C., Dong Woo L., Jung-IL S., *Hybrid approach to improve the flame-retardant and thermal properties of sustainable biocomposites used in outdoor engineering applications*, Composites Part A: Applied Science and Manufacturing, vol. 152, p. 106674, doi: 10.1016/j.compositesa.2021.106674, ian. 2022.

[38]. Pujar V., Devarajaiah R. M., Suresha B., Bharat V., *A review on mechanical and wear properties of fiber-reinforced thermoset composites with ceramic and lubricating fillers*, Materials Today: Proceedings, p. S2214785321012967, doi: 10.1016/j.matpr.2021.02.214, mar. 2021.

[39]. Mahdi E., Hamouda A. M. S., *Energy absorption capability of composite hexagonal ring systems*, Materials & Design, vol. 34, p. 201-210, doi: 10.1016/j.matdes.2011.07.070, feb. 2012.

[40]. Swarup Mohanty S., Kumar Rout A., Kumar Jesthi D., Chandra Routara B., Kumar Nayak R., *Evaluation of mechanical and wear performance of glass/carbon fiber reinforced polymer hybrid composite*, Materials Today: Proceedings, vol. 5, nr. 9, p. 19854-19861, doi: 10.1016/j.matpr.2018.06.350, 2018.

[41]. A. Tabatabaeian, Ghasemi A. R., *Curvature changes and weight loss of polymeric nano-composite plates with consideration of the thermal cycle fatigue effects and different resin types: An experimental approach*, Mechanics of Materials, vol. 131, p. 69-77, doi: 10.1016/j.mechmat.2019.01.017, apr. 2019.

[42]. Hu J., Liu Y., Zhang S., Tang B., *Novel designed core–shell nanofibers constituted by single element-doped $BaTiO_3$ for high-energy–density polymer nanocomposites*, Chemical Engineering

Journal, vol. 428, p. 131046, doi: 10.1016/j.cej.2021.131046, ian. 2022.
[43]. Suhas S., Raju M. J. S., Vijayan D. S., *Natural fibre reinforcement experimental study in polymer composite*, Materials Today: Proceedings, vol. 45, p. 6655-6659, doi: 10.1016/j.matpr.2020.12.051, 2021.
[44]. Sliseris J., Yan L., Kasal B., *Numerical modelling of flax short fibre reinforced and flax fibre fabric reinforced polymer composites*, Composites Part B: Engineering, vol. 89, p. 143-154, doi: 10.1016/j.compositesb.2015.11.038, mar. 2016.
[45]. Oliveira M. S., *et al.*, *Statistical analysis of notch toughness of epoxy matrix composites reinforced with fique fabric*, Journal of Materials Research and Technology, vol. 8, nr. 6, p. 6051-6057, doi: 10.1016/j.jmrt.2019.09.079, nov. 2019.
[46]. Mu B., Yang Y., *Complete separation of colorants from polymeric materials for cost-effective recycling of waste textiles*, Chemical Engineering Journal, vol. 427, p. 131570, doi: 10.1016/j.cej.2021.131570, ian. 2022.
[47]. Singh M. K., Singh A., *Fibers and fiber-forming polymers*, Characterization of Polymers and Fibres, Elsevier, p. 1-27, doi: 10.1016/B978-0-12-823986-5.00002-6, 2022.
[48]. Rizwan K., Rasheed T., Bilal M., *Nano-biodegradation of polymers*, Biodegradation and Biodeterioration at the Nanoscale, Elsevier, p. 213-238, doi: 10.1016/B978-0-12-823970-4.00010-5, 2022.
[49]. Benin S. R., Kannan S., Bright R. J., Jacob Moses A., *A review on mechanical characterization of polymer matrix composites & its effects reinforced with various natural fibres*, Materials Today: Proceedings, vol. 33, p. 798-805, doi: 10.1016/j.matpr.2020.06.259, 2020.
[50]. Chandekar H., Chaudhari V., Waigaonkar S., *A review of jute fiber reinforced polymer composites*, Materials Today: Proceedings, vol. 26, p. 2079-2082, doi: 10.1016/j.matpr.2020.02.449, 2020.
[51]. Miller W., Ren Z., Smith C. W., Evans K. E., *A negative Poisson's ratio carbon fibre composite using a negative Poisson's ratio yarn reinforcement*, Composites Science and Technology, vol. 72, nr. 7, p. 761-766, doi: 10.1016/j.compscitech.2012.01.025, apr. 2012.
[52]. Treutenaere S., Lauro F., Bennani B., Haugou G., Matsumoto T., Mottola E., *Constitutive modelling of the strain-rate dependency of fabric reinforced polymers*, International Journal of Impact Engineering, vol. 108, p. 361-369, doi: 10.1016/j.ijimpeng.2017.04.010, oct. 2017.
[53]. Andrew J. J., Srinivasan S. M., Arockiarajan A., Dhakal H. N., *Parameters influencing the impact response of fiber-reinforced polymer matrix composite materials: A critical review*, Composite Structures, vol. 224, p. 111007, doi: 10.1016/j.compstruct.2019.111007, sep. 2019.
[54]. Koohbor B., Ravindran S., Kidane A., *Experimental determination of Representative Volume Element (RVE) size in woven composites*, Optics and Lasers in Engineering, vol. 90, p. 59-71, doi: 10.1016/j.optlaseng.2016.10.001, mar. 2017.
[55]. Mahadik Y., Hallett S. R., *Finite element modelling of tow geometry in 3D woven fabrics*, Composites Part A: Applied Science and Manufacturing, vol. 41, nr. 9, p. 1192-1200, doi: 10.1016/j.compositesa.2010.05.001, sep. 2010.
[56]. Xu W., Waas A. M., *Fracture toughness of woven textile composites*, Engineering Fracture Mechanics, vol. 169, p. 184-188, doi: 10.1016/j.engfracmech.2016.11.027, ian. 2017.
[57]. Green S. D., Matveev M. Y., Long A. C., Ivanov D., Hallett S. R., *Mechanical modelling of 3D woven composites considering realistic unit cell geometry*, Composite Structures, vol. 118, p. 284-293, doi: 10.1016/j.compstruct.2014.07.005, dec. 2014.
[58]. Saleh M. N., Lubineau G., Potluri P., Withers P. J., Soutis C., *Micro-mechanics based damage mechanics for 3D orthogonal woven composites: Experiment and numerical modelling*, Composite Structures, vol. 156, p. 115-124, doi: 10.1016/j.compstruct.2016.01.021, nov. 2016.
[59]. Ansar M., Xinwei W., Chouwei Z., *Modeling strategies of 3D woven composites: A review*, Composite Structures, vol. 93, no. 8, p. 1947-1963, doi: 10.1016/j.compstruct.2011.03.010, iul. 2011.
[60]. Liu X., Tang T., Yu W., Pipes R. B., *Multiscale modeling of viscoelastic behaviors of textile composites*, International Journal of Engineering Science, vol. 130, p. 175-186, doi: 10.1016/j.ijengsci.2018.06.003, sep. 2018.
[61]. Mulay S. S., Udhayaraman R., *On the constitutive modelling and damage behaviour of plain woven textile composite*, International Journal of Solids and Structures, vol. 156-157, p. 73-86, doi: 10.1016/j.ijsolstr.2018.08.002, ian. 2019.
[62]. Mohd Yusoff N. H., Irene Teo L.-R., Phang S. J., Wong V.-L., Cheah K. H., Lim S.-S., *Recent Advances in Polymer-based 3D Printing for Wastewater Treatment Application: An Overview*, Chemical Engineering Journal, vol. 429, p. 132311, doi: 10.1016/j.cej.2021.132311, feb. 2022.
[63]. Feld N., Coussa F., Delattre B., *A novel approach for the strain rate dependent modelling of woven composites*, Composite Structures, vol. 192, p. 568-576, doi: 10.1016/j.compstruct.2018.03.053, mai 2018.
[64]. Machado M., Fischlschweiger M., Major Z., *A rate-dependent non-orthogonal constitutive model for describing shear behaviour of woven reinforced thermoplastic composites*, Composites Part A: Applied Science and Manufacturing, vol. 80, p. 194-203, doi: 10.1016/j.compositesa.2015.10.028, ian. 2016.
[65]. Pant S., Laliberte J., Martinez M., Rocha B., *Derivation and experimental validation of Lamb wave equations for an n-layered anisotropic composite laminate*, Composite Structures, vol. 111, p. 566-579, doi: 10.1016/j.compstruct.2014.01.034, mai 2014.
[66]. Todor M.-P., Kiss I., Cioata V. G., *Development of fabric-reinforced polymer matrix composites using bio-based components from post-consumer textile waste*, Materials Today: Proceedings, vol. 45, p. 4150-4156, doi: 10.1016/j.matpr.2020.11.927, 2021.
[67]. Pant S., Laliberte J., Martinez M., Rocha B., Ancrum D., *Effects of composite lamina properties on fundamental Lamb wave mode dispersion characteristics*, Composite Structures, vol. 124, p. 236-252, doi: 10.1016/j.compstruct.2015.01.017, iun. 2015.
[68]. Gereke T., Döbrich O., Hübner M., Cherif C., *Experimental and computational composite textile reinforcement forming: A review*, Composites Part A: Applied Science and Manufacturing, vol. 46, p. 1-10, doi: 10.1016/j.compositesa.2012.10.004, mar. 2013.
[69]. Udhayaraman R., Mulay S. S., *Multi-scale approach based constitutive modelling of plain woven textile composites*, Mechanics of Materials, vol. 112, p. 172-192, doi: 10.1016/j.mechmat.2017.06.007, sep. 2017.
[70]. Wang L., *et al.*, *Progressive failure analysis of 2D woven composites at the meso-micro scale*, Composite Structures, vol. 178, p. 395-405, doi: 10.1016/j.compstruct.2017.07.023, oct. 2017.
[71]. Patnaik P. K., Swain P. T. R., Mishra S. K., Purohit A., Biswas S., *Recent developments on characterization of needle-punched nonwoven fabric reinforced polymer composites – A review*, Materials Today: Proceedings, vol. 26, p. 466-470, doi: 10.1016/j.matpr.2019.12.086, 2020.
[72]. Remanan S., Das T. K., Das N. C., *Graphene as a reinforcement in thermoset resins*, Polymer Nanocomposites Containing Graphene, Elsevier, p. 317-341, doi: 10.1016/B978-0-12-821639-2.00012-4, 2022.
[73]. Machado M., Murenu L., Fischlschweiger M., Major Z., *Analysis of the thermomechanical shear behaviour of woven-reinforced thermoplastic-matrix composites during forming*, Composites Part A: Applied Science and Manufacturing, vol. 86, p. 39-48, doi: 10.1016/j.compositesa.2016.03.032, iul. 2016.
[74]. Behera B. K., Dash B. P., *Mechanical behavior of 3D woven composites*, Materials & Design, vol. 67, p. 261-271, doi: 10.1016/j.matdes.2014.11.020, feb. 2015.
[75]. Nishida H., Carvelli V., Fujii T., Okubo K., *Quasi-static and fatigue performance of carbon fibre reinforced highly polymerized thermoplastic epoxy*, Composites Part B: Engineering, vol. 144, p. 163-170, doi: 10.1016/j.compositesb.2018.03.002, iul. 2018.

[76]. Verma D., Sharma M., Jain S., *An introduction to high-performance advanced polymers composites, their types, processing, and applications in automotive industries*, Sustainable Biopolymer Composites, Elsevier, p. 3-26, doi: 10.1016/B978-0-12-822291-1.00004-X, 2022.

[77]. Kulkarni P., Mali K. D., Singh S., *An overview of the formation of fibre waviness and its effect on the mechanical performance of fibre reinforced polymer composites*, Composites Part A: Applied Science and Manufacturing, vol. 137, p. 106013, doi: 10.1016/j.compositesa.2020.106013, oct. 2020.

[78]. Martínez-Hergueta F., Ares D., Ridruejo A., Wiegand J., Petrinic N., *Modelling the in-plane strain rate dependent behaviour of woven composites with special emphasis on the non-linear shear response*, Composite Structures, vol. 210, p. 840-857, doi: 10.1016/j.compstruct.2018.12.002, feb. 2019.

[79]. Kenari M. A., Verma D., *An introduction to self-healing of polymer composite materials and conventional repairing process*, Sustainable Biopolymer Composites, Elsevier, p. 155-172, doi: 10.1016/B978-0-12-822291-1.00003-8, 2022.

[80]. Naser M. Z., Hawileh R. A., Abdalla J. A., *Fiber-reinforced polymer composites in strengthening reinforced concrete structures: A critical review*, Engineering Structures, vol. 198, p. 109542, doi: 10.1016/j.engstruct.2019.109542, nov. 2019.

[81]. Meng W., Khayat K. H., Bao Y., *Flexural behaviors of fiber-reinforced polymer fabric reinforced ultra-high-performance concrete panels*, Cement and Concrete Composites, vol. 93, p. 43-53, doi: 10.1016/j.cemconcomp.2018.06.012, oct. 2018.

[82]. Bal B. C., *Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber*, Construction and Building Materials, vol. 51, p. 9-14, doi: 10.1016/j.conbuildmat.2013.10.041, ian. 2014.

[83]. Hegemier G., Stewart L., *Application of fiber-reinforced polymers to reinforced concrete bridges*, Innovative Bridge Design Handbook, Elsevier, p. 933-950. doi: 10.1016/B978-0-12-823550-8.00034-2, 2022.

[84]. Wu Y., Li C., Chen T., Qiu R., Liu W., *Photo-curing 3D printing of micro-scale bamboo fibers reinforced palm oil-based thermosets composites*, Composites Part A: Applied Science and Manufacturing, vol. 152, p. 106676, doi: 10.1016/j.compositesa.2021.106676, ian. 2022.

[85]. Kubo G., Matsuda T., Sato Y., *A novel basic cell modeling method for elastic-viscoplastic homogenization analysis of plain-woven laminates with nesting*, International Journal of Mechanical Sciences, vol. 146-147, p. 497-506, doi: 10.1016/j.ijmecsci.2018.01.007, oct. 2018.

[86]. Domun N., *et al.*, *Ballistic impact behaviour of glass fibre reinforced polymer composite with 1D/2D nanomodified epoxy matrices*, Composites Part B: Engineering, vol. 167, p. 497-506, doi: 10.1016/j.compositesb.2019.03.024, iun. 2019.

[87]. Fiore V., Valenza A., *Epoxy resins as a matrix material in advanced fiber-reinforced polymer (FRP) composites*, Advanced Fibre-Reinforced Polymer (FRP) Composites for Structural Applications, Elsevier, p. 88-121. doi: 10.1533/9780857098641.1.88, 2013.

[88]. Ali H. T., *et al.*, *Fiber reinforced polymer composites in bridge industry*, Structures, vol. 30, p. 774-785, doi: 10.1016/j.istruc.2020.12.092, apr. 2021.

[89]. Zhao S., Song Z., Espinosa H. D., *Modelling and Analyses of Fiber Fabric and Fabric-Reinforced Polymers under Hypervelocity Impact Using Smooth Particle Hydrodynamics*, International Journal of Impact Engineering, vol. 144, p. 103586, doi: 10.1016/j.ijimpeng.2020.103586, oct. 2020.

[90]. Shakir Abbood I., aldeen Odaa S., Hasan K. F., Jasim M. A., *Properties evaluation of fiber reinforced polymers and their constituent materials used in structures – A review*, Materials Today: Proceedings, vol. 43, p. 1003-1008, doi: 10.1016/j.matpr.2020.07.636, 2021.

[91]. Luo G., Li X., Zhou Y., Sui L., Chen C., *Replacing steel stirrups with natural fiber reinforced polymer stirrups in reinforced concrete Beam: Structural and environmental performance*, Construction and Building Materials, vol. 275, p. 122172, doi: 10.1016/j.conbuildmat.2020.122172, mar. 2021.

[92]. Cheon J., Lee M., Kim M., *Study on the stab resistance mechanism and performance of the carbon, glass and aramid fiber reinforced polymer and hybrid composites*, Composite Structures, vol. 234, p. 111690, doi: 10.1016/j.compstruct.2019.111690, feb. 2020.

[93]. Forintos N., Czigany T., *Multifunctional application of carbon fiber reinforced polymer composites: Electrical properties of the reinforcing carbon fibers – A short review*, Composites Part B: Engineering, vol. 162, p. 331-343, doi: 10.1016/j.compositesb.2018.10.098, apr. 2019.

[94]. Morampudi P., Namala K. K., Gajjela Y. K., Barath M., Prudhvi G., *Review on glass fiber reinforced polymer composites*, Materials Today: Proceedings, vol. 43, p. 314-319, doi: 10.1016/j.matpr.2020.11.669, 2021.

[95]. Carpenter A. J., Chocron S., Anderson C. E., *Bridging the scales: Continuum-based material constitutive modeling of mechanical and ballistic test data from composites and fabrics*, International Journal of Impact Engineering, vol. 120, p. 31-45, doi: 10.1016/j.ijimpeng.2018.05.005, oct. 2018.

[96]. Beauson J., Schillani G., Van der Schueren L., Goutianos S., *The effect of processing conditions and polymer crystallinity on the mechanical properties of unidirectional self-reinforced PLA composites*, Composites Part A: Applied Science and Manufacturing, vol. 152, p. 106668, doi: 10.1016/j.compositesa.2021.106668, ian. 2022.

[97]. Matsuda T., Goto K., Kubota N., Ohno N., *Negative through-the-thickness Poisson's ratio of elastic–viscoplastic angle-ply carbon fiber-reinforced plastic laminates: Homogenization analysis*, International Journal of Plasticity, vol. 63, p. 152-169, doi: 10.1016/j.ijplas.2014.05.007, dec. 2014.

[98]. Olave M., Vara I., Usabiaga H., Aretxabaleta L., Lomov S. V., Vandepitte D., *Nesting effect on the mode II fracture toughness of woven laminates*, Composites Part A: Applied Science and Manufacturing, vol. 74, p. 174-181, doi: 10.1016/j.compositesa.2015.03.020, iul. 2015.

[99]. Stephen I., Hughes E., Das S., *Reinforced concrete beams strengthened with basalt fibre fabric – A parametric study*, Structures, vol. 27, p. 309-318, doi: 10.1016/j.istruc.2020.05.008, oct. 2020.

[100]. Azimpour-Shishevan F., Akbulut H., Mohtadi-Bonab M. A., *Synergetic effects of carbon nanotube and graphene addition on thermo-mechanical properties and vibrational behavior of twill carbon fiber reinforced polymer composites*, Polymer Testing, vol. 90, p. 106745, doi: 10.1016/j.polymertesting.2020.106745, oct. 2020.

[101]. Hamoutami J. E., Moustachi O. E. K., *The behavior of a reinforced concrete portal frame treated by carbon fiber reinforced polymer (CFRP)*, Materials Today: Proceedings, vol. 45, p. 7697-7705, doi: 10.1016/j.matpr.2021.03.222, 2021.

[102]. Manocha L. M., *Carbon Based Materials*, Encyclopedia of Materials: Metals and Allloys, Elsevier, p. 394-419, doi: 10.1016/B978-0-12-819726-4.00098-3, 2022.

[103]. Ascione F., Lamberti M., Napoli A., Razaqpur G., Realfonzo R., *An experimental investigation on the bond behavior of steel reinforced polymers on concrete substrate*, Composite Structures, vol. 181, p. 58-72, doi: 10.1016/j.compstruct.2017.08.063, dec. 2017.

[104]. Yan L., Kasal B., Huang L., *A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering*, Composites Part B: Engineering, vol. 92, p. 94-132, doi: 10.1016/j.compositesb.2016.02.002, mai 2016.

[105]. Sethu Ramalingam P., Mayandi K., Srinivasan T., Jerin Leno I., Ravi R., Suresh G., *A study on E-Glass fiber reinforced interpenetrating polymer network (vinylester/polyurethane) laminate's flexural analysis*, Materials Today: Proceedings, vol. 33, p. 854-858, doi: 10.1016/j.matpr.2020.06.330, 2020.

[106]. Albert Seldon P., Abilash N., *Appraisal on Varied Natural and Artificial Fiber Reinforced Polymeric Composites*, Materials

Today: Proceedings, vol. 22, p. 3213-3219, doi: 10.1016/j.matpr.2020.03.459, 2020.
[107]. Ferreira Batista M., Basso I., de Assis Toti F., Roger Rodrigues A., Ricardo Tarpani J., *Cryogenic drilling of carbon fibre reinforced thermoplastic and thermoset polymers*, Composite Structures, vol. 251, p. 112625, doi: 10.1016/j.compstruct.2020.112625, nov. 2020.
[108]. Zhang C., Zheng D., Song G.-L., Guo Y., Liu M., Kia H., *Influence of microstructure of carbon fibre reinforced polymer on the metal in contact*, Journal of Materials Research and Technology, vol. 9, nr. 1, p. 560-573, doi: 10.1016/j.jmrt.2019.10.085, ian. 2020.
[109]. Miura M., Shindo Y., Narita F., Watanabe S., Suzuki M., *Mode III fatigue delamination growth of glass fiber reinforced polymer woven laminates at cryogenic temperatures*, Cryogenics, vol. 49, nr. 8, p. 407-412, doi: 10.1016/j.cryogenics.2009.05.004, aug. 2009.
[110]. Zhang B., Jia L., Tian M., Ning N., Zhang L., Wang W., *Surface and interface modification of aramid fiber and its reinforcement for polymer composites: A review*, European Polymer Journal, vol. 147, p. 110352, doi: 10.1016/j.eurpolymj.2021.110352, mar. 2021.
[111]. Dong K., Peng X., Zhang J., Gu B., Sun B., *Temperature-dependent thermal expansion behaviors of carbon fiber/epoxy plain woven composites: Experimental and numerical studies*, Composite Structures, vol. 176, p. 329-341, doi: 10.1016/j.compstruct.2017.05.036, sep. 2017.
[112]. Espadas-Escalante J. J., van Dijk N. P., Isaksson P., *The effect of free-edges and layer shifting on intralaminar and interlaminar stresses in woven composites*, Composite Structures, vol. 185, p. 212-220, doi: 10.1016/j.compstruct.2017.11.014, feb. 2018.
[113]. Laffan M. J., Pinho S. T., Robinson P., McMillan A. J., *Translaminar fracture toughness testing of composites: A review*, Polymer Testing, vol. 31, nr. 3, p. 481-489, doi: 10.1016/j.polymertesting.2012.01.002, mai 2012.
[114]. Sacchetti F., Grouve W. J. B., Warnet L. L., Villegas I. F., *Woven fabric composites: Can we peel it?*, Procedia Structural Integrity, vol. 2, p. 245-252, doi: 10.1016/j.prostr.2016.06.032, 2016.
[115]. Tambe P., Tanniru M., Sai B. L. N. K., *Structural/load bearing characteristics of polymer-graphene composites*, Polymer Nanocomposites Containing Graphene, Elsevier, p. 379-400, doi: 10.1016/B978-0-12-821639-2.00005-7, 2022.
[116]. Bhagabati P., Rahaman M., *Structure-property relationship in polymer-graphene composites*, Polymer Nanocomposites Containing Graphene, Elsevier, p. 299-315, doi: 10.1016/B978-0-12-821639-2.00016-1, 2022.
[117]. Pritzkow W. E. C., Wehner F., Koch D., *Oxide Fiber Reinforced Oxide Ceramic Matrix Composite – An Alternative to Metallic Alloys at High Temperature*, Encyclopedia of Materials: Metals and Allloys, Elsevier, p. 425-441, doi: 10.1016/B978-0-12-819726-4.00040-5, 2022.
[118]. Park J. K., Kim M. O., *The effect of different exposure conditions on the pull-off strength of various epoxy resins*, Journal of Building Engineering, vol. 38, p. 102223, doi: 10.1016/j.jobe.2021.102223, iun. 2021.
[119]. da Silva L. R. R., *et al.*, *Bio-based one-component epoxy resin: Novel high-performance anticorrosive coating from agro-industrial byproduct*, Progress in Organic Coatings, vol. 167, p. 106861, doi: 10.1016/j.porgcoat.2022.106861, iun. 2022.
[120]. Liu Z., Xie C., Tuo X., *Laminated aramid nanofiber aerogel reinforced epoxy resin composite*, Materials Today Communications, vol. 31, p. 103376, doi: 10.1016/j.mtcomm.2022.103376, iun. 2022.
[121]. Feng Q.-K., *et al.*, *Particle packing theory guided multiscale alumina filled epoxy resin with excellent thermal and dielectric performances*, Journal of Materiomics, vol. 8, nr. 5, p. 1058-1066, doi: 10.1016/j.jmat.2022.02.008, sep. 2022.
[122]. Ruan K., Zhong X., Shi X., Dang J., Gu J., *Liquid crystal epoxy resins with high intrinsic thermal conductivities and their composites: A mini-review*, Materials Today Physics, vol. 20, p. 100456, doi: 10.1016/j.mtphys.2021.100456, sep. 2021.
[123]. Morsch S., Kefallinou Z., Liu Y., Lyon S. B., Gibbon S. R., *Controlling the nanostructure of epoxy resins: Reaction selectivity and stoichiometry*, Polymer, vol. 143, p. 10-18, doi: 10.1016/j.polymer.2018.03.065, mai 2018.
[124]. Zhao H., Xu S., Guo A., Li J., Liu D., *The Curing Kinetics Analysis of Four Epoxy Resins Using a Diamine Terminated Polyether as Curing Agent*, Thermochimica Acta, vol. 702, p. 178987, doi: 10.1016/j.tca.2021.178987, aug. 2021.
[125]. Wang X., Amason A.-C., Lei Y., Gabbard R., Wieland J. A., Gross R. A., *Bio-based alternative for encapsulating fragrance oils in epoxy resin microcapsules*, Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 640, p. 128387, doi: 10.1016/j.colsurfa.2022.128387, mai 2022.
[126]. Lorenz N., *et al.*, *Characterization and modeling cure- and pressure-dependent thermo-mechanical and shrinkage behavior of fast curing epoxy resins*, Polymer Testing, vol. 108, p. 107498, doi: 10.1016/j.polymertesting.2022.107498, apr. 2022.
[127]. Ratna D., *Chemistry and general applications of thermoset resins*, Recent Advances and Applications of Thermoset Resins, Elsevier, p. 1-172, doi: 10.1016/B978-0-323-85664-5.00006-5, 2022.
[128]. Wan X., Demir B., An M., Walsh T. R., Yang N., *Thermal conductivities and mechanical properties of epoxy resin as a function of the degree of cross-linking*, International Journal of Heat and Mass Transfer, vol. 180, p. 121821, doi: 10.1016/j.ijheatmasstransfer.2021.121821, dec. 2021.
[129]. Opelt C. V., Coelho L. A. F., *On the pseudo-ductility of nanostructured epoxy resins*, Polymer Testing, vol. 78, p. 105961, doi: 10.1016/j.polymertesting.2019.105961, sep. 2019.
[130]. Bhadra S., Nair S., *Tailor-made one-part epoxy resin for tire compound to improve ride and handling and reduce rolling resistance*, Materials Today: Proceedings, vol. 62, p. 7002-7006, doi: 10.1016/j.matpr.2021.12.544, 2022.
[131]. Cui M., Qing Y., Yang Y., Long C., Liu C., *Nanofunctionalized composite-crosslinked epoxy resin for eco-friendly and robust superhydrophobic coating against contaminants*, Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 633, p. 127914, doi: 10.1016/j.colsurfa.2021.127914, ian. 2022.
[132]. Li Y., Huang K., Yu H., Hao L., Guo L., *Experimentally validated phase-field fracture modeling of epoxy resins*, Composite Structures, vol. 279, p. 114806, doi: 10.1016/j.compstruct.2021.114806, ian. 2022.
[133]. Chen C., *et al.*, *Comparative analysis of natural fiber reinforced polymer and carbon fiber reinforced polymer in strengthening of reinforced concrete beams*, Journal of Cleaner Production, vol. 263, p. 121572, doi: 10.1016/j.jclepro.2020.121572, aug. 2020.
[134]. Huayamares S., Grund D., Taha I., *Comparison between 3-point bending and torsion methods for determining the viscoelastic properties of fiber-reinforced epoxy*, Polymer Testing, vol. 85, p. 106428, doi: 10.1016/j.polymertesting.2020.106428, mai 2020.
[135]. Mourad A.-H. I., Idrisi A. H., Zaaroura N., Sherif M. M., Fouad H., *Damage assessment of nanofiller-reinforced woven kevlar KM2plus/Epoxy resin laminated composites*, Polymer Testing, vol. 86, p. 106501, doi: 10.1016/j.polymertesting.2020.106501, iun. 2020.
[136]. Santhosh G., Rao R. N., *Effect of castor oil on mechanical and thermal behaviours of hybrid fibres reinforced epoxy based polymer composites*, Materials Today: Proceedings, p. S2214785321017417, doi: 10.1016/j.matpr.2021.02.594, mar. 2021.
[137]. Yang B., Wang S., Wang Y., *Effect of Nesting in Laminates on the Through-Thickness Permeability of Woven Fabrics*, Appl Compos Mater, vol. 25, nr. 5, p. 1237-1253, doi: 10.1007/s10443-018-9699-8, oct. 2018.
[138]. Dhanush Kumar K. K., Ashish B. V., Vinod B., *Evaluation of tensile properties of hybrid kevlar-glass reinforced*

epoxy composite for multi holes configuration, Materials Today: Proceedings, vol. 44, p. 1065-1070, doi: 10.1016/j.matpr.2020.11.180, 2021.

[139]. Valença S. L., Griza S., de Oliveira V. G., Sussuchi E. M., de Cunha F. G. C., *Evaluation of the mechanical behavior of epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabric*, Composites Part B: Engineering, vol. 70, p. 1-8, doi: 10.1016/j.compositesb.2014.09.040, mar. 2015.

[140]. Xu W., Guo Z. Z., Yu Y., Xiong J., Gao Y., *Experimental and analytical characterizations of finite interlaminar crack growth of 2D woven textile composites*, Composite Structures, vol. 206, p. 713-721, doi: 10.1016/j.compstruct.2018.08.050, dec. 2018.

[141]. Velmurugan V., Dinesh Kumar D., Thanikaikarasan S., *Experimental evaluation of mechanical properties of natural fibre reinforced polymer composites*, Materials Today: Proceedings, vol. 33, p. 3383-3388, doi: 10.1016/j.matpr.2020.05.190, 2020.

[142]. Murugan R., Ramesh R., Padmanabhan K., *Investigation on Static and Dynamic Mechanical Properties of Epoxy Based Woven Fabric Glass/Carbon Hybrid Composite Laminates*, Procedia Engineering, vol. 97, p. 459-468, doi: 10.1016/j.proeng.2014.12.270, 2014.

[143]. Misumi J., Oyama T., *Low viscosity and high toughness epoxy resin modified by in situ radical polymerization method for improving mechanical properties of carbon fiber reinforced plastics*, Polymer, vol. 156, p. 1-9, doi: 10.1016/j.polymer.2018.09.050, nov. 2018.

[144]. Kiran M. D., Govindaraju H. K., Yadhav B. R. L., Suresha B., Keerthi Kumar N., *Fracture toughness study of epoxy composites reinforced with carbon fibers with various thickness*, Materials Today: Proceedings, p. S2214785321013584, doi: 10.1016/j.matpr.2021.02.271, mar. 2021.

[145]. Goli E., *et al.*, *Frontal polymerization of unidirectional carbon-fiber-reinforced composites*", Composites Part A: Applied Science and Manufacturing, vol. 130, p. 105689, doi: 10.1016/j.compositesa.2019.105689, mar. 2020.

[146]. Dai S., Cunningham P. R., Marshall S., Silva C., *Influence of fibre architecture on the tensile, compressive and flexural behaviour of 3D woven composites*, Composites Part A: Applied Science and Manufacturing, vol. 69, p. 195-207, doi: 10.1016/j.compositesa.2014.11.012, feb. 2015.

[147]. Zheng C., Duan F., Liang S., *Manufacturing and mechanical performance of novel epoxy resin matrix carbon fiber reinforced damping composites*, Composite Structures, vol. 256, p. 113099, doi: 10.1016/j.compstruct.2020.113099, ian. 2021.

[148]. Koirala P., van de Werken N., Lu H., Baughman R. H., Ovalle-Robles R., Tehrani M., *Using ultra-thin interlaminar carbon nanotube sheets to enhance the mechanical and electrical properties of carbon fiber reinforced polymer composites*, Composites Part B: Engineering, vol. 216, p. 108842, doi: 10.1016/j.compositesb.2021.108842, 2021.