A SURVEY ON YIELD CRITERIA FOR POLYMER MATRIX FIBER-REINFORCED COMPOSITES

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Keywords: Fiber-Reinforced Polymer Composites, Criteria, Yield, Failure, Deformation

ABSTRACT

Because of their mechanical properties, composite/compound materials have been adapted in numerous products and industries. To facilitate the introduction of these materials to different applications, predicting their behaviors under mechanical loads is of great interest. Considering their nonlinear and anisotropic deformations through different loading scenarios, predicting their yield/failure point with precision is challenging. Nonetheless, in the past decades, several methods and criteria have been developed for predicting composites' behavior based on their material combinations and the type of stress to which they are prone. As a meta-review, this paper will be surveying the saturated trends on the criteria which have been developed for polymer matrix composites (PMC), particularly those reinforced with fibers (FR).

Due to the broad scope of the topic, the primary focus has been the identification of the correct failure criteria for polymer-matrix fiber-reinforced composites (PMFRC) in different projects, as the existing methods, depending on the application, may be far from predicting the outcome of the experiments. Based on this, the topic has broken down into several subsections to provide a road map in the literature, that would facilitate future studies on PMFRC to use the most proper criterion for specific applications.

1 INTRODUCTION

Polymer matrix composites (PMC) have been extensively used to manufacture numerous engineering components by many industries. This wide usage can be attributed to their lightweight, high strength, exceptional corrosion resistance, and acoustic properties, among other outstanding properties, especially when compared with several metallic and alloy materials. Furthermore, their applications are rampant in automobile, marine, power/energy, telecommunication, security, military, sport/game, and aerospace industries, to mention but a few. If we classify PMC by the type of their reinforcement material, there are structural composites, particle-reinforced, or fiber-reinforced composites. The subject of this paper, Polymer Matrix Fiber Reinforced Composites (PMFRC), or in layman term Fiber Reinforced Plastics (FRP) are materials consisting of discontinuous fibers or continuous filaments, infiltrated/laminated with a thermoplastic or a thermoset polymer (the terms FRP and PMFRC have been used interchangeably in the following). After several manufacturing processes, the result is to be a robust and lightweight part that can withstand large loads and functional cycles. Not to mention, the possibilities of adding several functionalities make FRP more enticing for technology and research. Moreover, challenges such as their inhomogeneity, microcracks, delamination, etc., in addition to requiring multiple manufacturing steps, and considering the combination of different reinforcement fibers with various polymers in diverse applications, can only complicate introducing these materials to the industry.

Failure criteria and modeling the materials' behavior loadings have been significant research fields for over a century. The field has been through many noteworthy advancements. Various progressive models have been proposed to predict deformations of materials based on the stress to which they are susceptible in their lifetime. Because of their anisotropic nature and their nonlinear response to different loads, modeling FRP has been challenging and rewarding. Hence, many variants are involved in producing PMFRC, predicting their failure points, can reduce production costs alongside easing their utilization in industries.

A number of earlier studies proposed several methods predicting the biaxial behavior of composites and compared failure theories for laminates made of fiber-reinforced plastic. The studies by Hashin ([1], [2]), Puck [3], Cuntze [4], Chamis [5], Sandhu [6], Owen and Griffiths [7], Soni [8], Tsai[9], Tsai and Wu [10], Rowlands [11], Nahas [12], Chen and Mathews [13], and more are among these. Afterward, the main focus was mostly modifying these main analytical methods or repurposing them in a numerical strategy to predict the failure points more accurately. Also, having the World-Wide Failure Exercise (WWFE) in mind, determining the maturity level of theories for predicting the failure response of fiber-reinforced composites (FRC), the knowledge gap between theoreticians and design practitioners in this area has been closing. If three distinct stages (initial modeling, manufacturing, and function) in the life cycle of a part are assumed, FRP adaptation could benefit using yield criteria for any of these stages. Each criterion/model can show if the material is appealing for production and the lifetime of the part or not, which can maximize efficiency in the fabrication process. Because numerous criteria predicting the failure/deformation point of FRP have been proposed over recent years and several review articles surveyed each of these criteria over each of the aforementioned phases, the in-hand article tries to be a meta-review, introducing the saturated trends of the field, and reduce the complications to the new researchers while interring this topic.

2 METHODS

As a meta-review, or in other words, an overview of reviews, this literature tends to capture the most noteworthy trends in this field and represent what the areas of focus have been observing the subject. During this survey, review articles, theses, books, and journals have been collected with at least four novel approaches on this topic, however, it excludes those methods that haven't been covered in at least three separate review articles on the same topic. Keywords such as yield/failure/deformation/, criterion/ criteria/model/analyzing method, and PMFRC/ FRP have been sought after simultaneously during this research. Furthermore, this article takes the duration after the 2000s for its time limits. Three subfractions have been focused on this theme concerning before, during, and after production of the parts made out of FRP. Respectively, the initial material selection/design phase (including tensile, compressive, shear, and impact failure modeling), the manufacturing phase (with machining and forming deformation criteria), and ultimately the functional life cycle of the part (considering fatigue and tribological yield prediction), have been the finding areas of this overview. To mention the last specified limit in the research, the selected articles represented only the methods with several experimental back-ups. Referring to a few databases, Elsevier, Springer, EBSCO, Google Scholar, ScienceDirect, and Connected-Papers have been used to find the proper literature. In the end, this paper will not cover the whole of such a broad field, however, compasses a brief guide to some of the most cited reviews on the field.

3 RESULTS

As mentioned, three different subfractions have been surveyed in this article, observing the main needs in predicting the yield behaviors of PMFRC or other materials interacting with them in their life cycle. In the first phase, the prediction methods of raw strength of FRP were focused. Second, the review articles assessing the yield criterion/ models in the manufacturing phase of these materials gathered, and finally, predicting these materials' damage during their life cycle were investigated. Each section has been torn down into at least two other subcategories, each one predicting yield/failure/damage during a specific situation that tension applied to FRP. Figure 1 represents the subfractions and the subcategories of the findings.

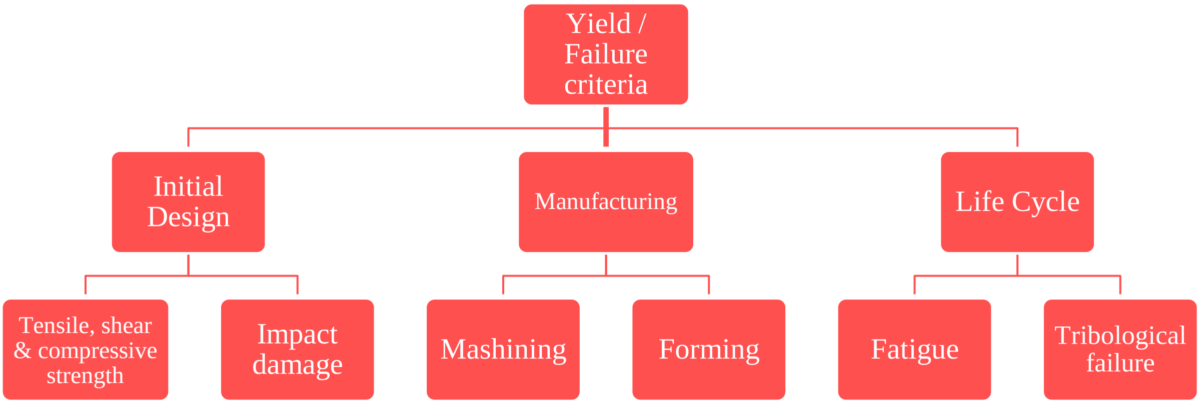

Figure 1: Research scope hierarchy, representing the proposed application phases of yield criteria and their saturated branches that have been mentioned in this meta review.

3.1 INITIAL DESIGN PHASE

In predicting the maximum strength of the final part, choosing an analysis method well suited to the prospective material is necessary. Modifying/substituting the general rules of mixture for FRP, several methods have been proposed to accurately predict tensile, shear, and compressive yield behavior as the basics, and furthermore, the impact resistance of these materials. In the following, review literature on these portions will be mentioned:

3.1.1 TENSILE, SHEAR AND COMPRESSIVE STRENGTH

Evaluating the methodology for fiber-reinforced composites' failure theories of R. M. Christensen [14] has presented a comprehensive survey. The lamina level failure criteria, which includes nominally aligned fibers in a matrix phase, was the focus of this study. In a coordinated study known as the World-Wide Failure Exercise, 12 of the top theories for predicting failure in composite laminates were put to the test against experimental data. The findings are summarized in a paper by M.J. Hinton et al [15]. They enumerate each theory's advantages and disadvantages and rank them according to how effective they are overall. In 2007 I. M Daniel et al. [16] have reviewed the most recent theories and methods for predicting and analyzing failure in composite materials. Limit or noninteractive, interactive, and failure mode-based theories are the categories that have been discussed, their applicability and validity have been assessed in this review. In 2011 Ku et al. [17] focused on natural fibers used for composites and compared the most accurate failure theories for predicting the strength and young modulus in different scenarios. A critical review has been published by R. Talreja assessing the trending failure theories for FRP. Rather than comparing the predicted tension-compression response of the material to the experimental data, this study looked into the assumptions of each criterion and proposed some modifications to each reviewed criterion. An overview of continuum damage models usage for simulating the intralaminar failure mechanisms in composite materials published by Forghani et al. [18]. In 2020 Fallahi et al. [19] have reviewed the methods predicting the mechanical response of fiber reinforced PMCs. Based on the increasing degree of complexity, methods have been categorized into four main classes: nonlinear elasticity models, elastic-plastic models, elastic-plastic- viscous models and damage-plasticity models. Many factors such as tension-compression asymmetry, viscous behavior, and interaction between stress components and effects of environmental factors on mechanical properties have briefly reviewed in this research.

3.1.2 IMPACT DAMAGE

In 2012, Lecce et al. [20] covered the recent approaches based on the finite element method on laminates progressive failure analysis. In this work, some practical solutions for the prediction of the damage after low-velocity impact were introduced. S. Abrate et al. reviewed the damage foreseeing methods based on the cohesive zone model [21]. These criteria are used for the prediction of delaminations and matrix cracks on PMFRC. The work of Forghani et al. [18] dedicated a part to impact/ blast damage predicting methods in composite laminates. The presented models were covering the response of composite laminates to transverse dynamic loading from local impact, intra and inter-laminar cracking, etc. In 2018, Bogenfeld et al. [22] dedicated a section of their published book to predict progressive delamination via interface elements. In this section, damage prediction of FRCs prone to impact was mentioned, also, a benchmark study on the damage analysis of the low-velocity impact on composite laminates has been done. In 2022 M. Sadighi et al. [23] reviewed experimental studies related to “impact fatigue”, “multiple impacts”, and “repeated impacts” on FRP, along with articles discussing theoretical and numerical simulations for damage prediction in these phenomena.

3.2 MANUFACTURING PHASE

Researching yield criteria related to manufacturing processes of parts made of FRP, lead us to two subcategories. Methods regarding machining processes and forming processes, the optimum applies force of the tools, and the shape of the material after the machining/ forming procedures were the main focus of the findings:

3.2.1 MACHINING

A comprehensive review has been done on drilling multi-material stacks and modeling of tool failures in these processes by V. Krishnaraj et al. in 2004. [24] In 2006 A. M. Abrão et al. dedicated a reviewing research on the subject of drilling in PMFRC considering the optimal tool materials and geometry, optimum thrust force and torque, and the prospected quality of the machined holes.[25] In 2010, K. A. Kalzada et al. [26] thesis focused on the fiber-oriented failure mechanisms, during the machining of carbon fiber reinforced composites. He surveyed different modeling and analytical approaches for the interpretation of failure on these polymer matrix composites. In 2012 Liu et al. [27] presented a systematic review of drilling procedures in composite laminates focusing on prediction, assessment, and prevention of delamination in the process. Xu et al. [28] in 2016 had a review on FRP/Ti composite and foreseeing the behavior of these materials while drilling. In 2018, a review article on the milling process of PMCs has been published by P. Patel et al. [29]. The literature investigates speed, feed, and several other criteria for achieving the optimum intended failure on material while decreasing the tool damage. In 2021, editors I. Shyha and D. Huo gathered the relevant research on the machining of composite materials in a book [30]. In this book, 11 different articles were focusing on the machining of FRP and their yield modeling. Also in 2021, Hammed Sultan et al. published a book consisting of several articles on the subject of Machining and Machinability of PMFRCs. Failure analysis of the tools and materials have been one of the main focuses of this literature.[31]

3.2.2 FORMING

In 2013 Gereke et al. [32] reviewed the experimental characterization of the forming and the numerical methods for modeling the forming of textiles which later to be used in composites. The characterization of the shear behavior, as it is thought to be the most crucial property for textile reinforcement forming processes, has been investigated. In contrast, bending behavior, which was initially neglected in mechanical models, was found to be important for the simulation of wrinkles. In 2017 Boisse et al. [33] focused their review on the bias-extension test and presented the studies that have been done on the lack of verification of these hypotheses (slippage, tension in the yarns, effects of fiber bending). In the case of the bias-extension test, the effects of temperature, mesoscopic modeling, and tension locking have also been taken into account. In 2018 [34] Boisse et al. published a review of developments of the draping simulations In order to simulate textile reinforcements with shells. They surveyed some shell techniques that deviate from the accepted theories, which can accurately compute the rotations of the textile reinforcement norms. The study of Bussetta et al. [35] was about the numerical forming of composite material with continuous fiber reinforcement. Their review demonstrates that all numerical models of the formation process are computed at the macro-scale, despite the fact that certain models are defined with data from the meso-scale. The article published by Gong et al. [36] in 2020 reviews the literature on the characterization and simulation for thermo-stamping of 2D woven fabric-reinforced thermoplastics. A review presenting the state of the art of forming modeling methods for textile reinforcement and the corresponding experimental characterization methods developed was published by Liang et al. and Boisse et al. [37] The microscopic, mesoscopic, and macroscopic models are discussed in the survey. The main characteristics of the global and local processes, as well as the appropriate modeling techniques, are examined, and the value of the publications concerning thermo-stamping in FRTCs [38]. A portion of an extensive review by Brooks et al. [39] surveyed the effect of process parameters on the mechanical properties of formed FRP parts, with the highlighted trends and methodologies for finding optimum conditions in forming processes.

3.3 LIFE CYCLE PHASE

Predicting the functional life cycles of components has always been of great interest. Parts made of PMFRC are not apart from this matter. Utilizing progressive material models in the simulations over recent years, modeling tribological behavior and fatigue strength of FRP parts have been through a major improvement, leading to better material usage and reducing waste. A few of these proposed modeling/predicting methods have been surveyed in the review articles below:

3.3.1 FATIGUE

An early work by J. Degrieck and W. Van Paepegem [40] surveyed 141 references in the fatigue damage modeling of fiber-reinforced composite materials. They classified the issue into 3 sections of fatigue life models, phenomenological models and progressive damage models, surveying the most important models proposed during the last decades. Between the years 2010 and 2020, two editions of the book of A.P. Vasilopoulos have been published covering different aspects of fatigue modeling criterion and techniques predicting the life of composite structures [41]. In 2013 A comprehensive overview has been conducted by Wicaksono et al. [42] regarding the advances in fatigue and life prediction of fiber-reinforced composites. J.A. Pasco et al. [43] have published a critical review on the criteria of fatigue delamination in composites and adhesive bonds in the past 40 years. They believe (at that time) methods were too phenomenological, and a physics-based approach, elucidating the mechanisms is needed to fully understand the delamination growth. Mortazavian and Fatemi [44] have published a review on the modeling of fatigue behavior focusing on short fiber-reinforced polymer composites. In their study, they surveyed several microstructural related effects on the fatigue of the material. An overview of fatigue damage modeling techniques has been introduced by Sevenois et al. [45] for Textile Composites. A comparison between unidirectional composite modeling criteria has been conducted in this study. As for the extension of NU-Daniel theory first-ply yielding and failure (FPY and FPF), as well as the progressive failure of multidirectional laminates, were predicted in situ based on theoretical hypotheses and experimental results for various angle-ply laminates under various strain rates. Using the isolated lamina results as a starting point, the behavior of a lamina inside a multi-directional laminate was examined, and the stress state at the beginning of yielding and the damage saturation condition were discovered [46]. In 2018, a practical review surveying the state-of-the-art fatigue modeling methods for composite used in the blade of wind turbines has been published by Rubiella et al. [48]. In 2019, Jawaid et al. have wrote a comperhensivie book intending to close the gap in the published literature involving failure analysis of biocomposites, fiber-reinforced composites, and hybrid composites. This book covers fatigue delamination, deformation, effect of strain rate on the failure mechanisms, energy absorption and etc in the case of FRCs [47]. In 2022 M. Sadighi et al. [23] surveyed the fatigue prediction methods for FRP in the case of low-velocity impact. In 2022 Farazin et al. published an extensive study on strain dependence of glass fiber-reinforced plastics. In their review, they focused on the experimented behavior of long glass fibers and thermoset polymers under different strain rates separately and while combined in a composite. Ultimately, several analytical and numerical models have been surveyed for this kind of composite. [49].

3.3.2 TRIBOLOGICAL FAILURE

A comprehensive literature review on tribological behavior of polymer matrix composites made with natural fibers is presented by Shalwan et al. [50]. Different variants affecting the accuracy of prediction of tribology properties were surveyed in this study. In 2021 in their review, Marian et al. [51] dedicated a section to the current trend in the prediction of tribological behavior of thermoses matrix composite material using artificial intelligence and machine learning. A comprehensive overview has been published by Paturi et al. [52] on predicting the tribological behavior of FRP using artificial neural networks as the criteria. The recent advances in tribological damage and frictional life cycle analysis of composite materials have been mentioned in the work of Sose et al. [53] using machine learning methods. Moreover, material selection techniques using these approaches have been evaluated.

4 DISCUSSION

As the PMFRC will be adopted more and more in any application, or a new type of these materials will be invented, the substantial need for prediction of their mechanical behavior will grow. Building on that, the vast number of methods calculating these materials' yield points can make the field more overwhelming for researchers. Classification of the further application for a subject material can be a practical way to limit the area of the research, finding the most accurate and applicable criterion to predict the failure of a component.

The chronological perspective of the field can anticipate the popularity growth of more case-specified methods compared to generalized ones. Moreover, the criteria for dynamic failure scenarios such as impact, fatigue, and friction/tribology have been developed more over the years than the simple static criteria suggesting the shear and tensile strength of the material. The reason for this could be the hardships of providing actual experiments for dynamic failure in comparison to the common uniaxial/biaxial or shear strength test experiments.

To mention another trend, utilizing newer methods such as artificial intelligence, neural networks, and machine learning over recent years in a complex field such as tribology can be evidence promising their potential to be used in other situations of yield point prediction.

Finally, the distinguished phase between the three fractions of this study is the manufacturing phase. In contrast to the other portions of this paper, in the manufacturing phase, finding the optimum intentional stress leading to the yield/ failure of the FRP is the focus. Furthermore, the optimization studies in this section intend to decrease tool maintenance/ management costs or the quality of the end product made of FRP.

5 CONCLUSIONS

To this end, the authors of the in-hand paper have deconstructed the subject into multiple aspects, intending to create a comprehensive roadmap within the existing literature. Even though the mentioned categories and subcategories in this article cannot cover the whole field, they can show the most sought-after applications and the yield criteria for FRP. This meta-review can serve as a resource for future studies on the failure behaviors of PMFRC, enabling new researchers to deploy the most precise/usable criteria for their applications or to figure out what has been done so far to avoid parallel studies. By establishing such a framework, the investigation to find the accurate failure criterion can become less complicated and help the utilization of PMFRC.

ACKNOWLEDGEMENTS

This study was supported by Chair of Textile Technologies, Institute of Lightweight Structures in faculty of Mechanical Engineering at Technical University of Chemnitz.

REFERENCES

[1] Z. Hashin and A. Rotem, "A Fatigue Failure Criterion for Fiber Reinforced Materials".

[2] Z. Hashin and A. Rotem, "A Fatigue Failure Criterion for Fiber Reinforced Materials," *Journal of Composite Materials*, vol. 7, no. 4, pp. 448–464, Oct. 1973, doi: 10.1177/002199837300700404.

[3] A. Puck and H. Schürmann, "Failure analysis of FRP laminates by means of physically based phenomenological models".

[4] R. G. Cuntze, Ed., *Neue Bruchkriterien und Festigkeitsnachweise für unidirektionalen Faserkunststoffverbund unter mehrachsiger Beanspruchung: Modellbildung und Experimente,* Als Ms. gedr. in Fortschrittberichte VDI Reihe 5, Grund- und Werkstoffe, Kunststoffe, no. 506. Düsseldorf: VDI-Verl, 1997.

[5] C. C. Chamis, "Failure Criteria for Filamentary Composites," in *Composite Materials: Testing and Design*, S. Yurenka, Ed., 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International, 1969, pp. 336-336–16. doi: 10.1520/STP49826S.

[6] "Sandhu R S, 'A survey of failure theories of isotropic and anisotropic materials', AFFDL-TR_72–71, AD756889, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, USA, 1972".

[7] M. Owen and D. Rice, "Biaxial Strength Behavior of Glass-Reinforced Polyester Resins," in *Composite Materials: Testing and Design (6th Conference)*, I. Daniel, Ed., 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International, 1982, pp. 124-124–21. doi: 10.1520/STP28478S.

[8] S. R. Soni, "A Comparative Study of Failure Envelopes in Composite Laminates," *Journal of Reinforced Plastics and Composites*, vol. 2, no. 1, pp. 34–42, Jan. 1983, doi: 10.1177/073168448300200104.

[9] S. W. Tsai, "A Survey of Macroscopic Failure Criteria for Composite Materials," *Journal of Reinforced Plastics and Composites*, vol. 3, no. 1, pp. 40–62, Jan. 1984, doi: 10.1177/073168448400300102.

[10] S. W. Tsai and E. M. Wu, "A General Theory of Strength for Anisotropic Materials".

[11] G. C. Sih and A. M. Skudra, Eds., *Failure mechanics of composites*. in Handbook of composites, no. v. 3. Amsterdam ; New York : New York, NY, U.S.A: North-Holland ; Sole distributors for the U.S.A. and Canada, Elsevier Science Pub. Co, 1985.

[12] K. Reifsnider *et al.*, "Survey of Failure and Post-Failure Theories of Laminated Fiber-Renforced Composites," *J. Compos. Technol. Res.*, vol. 8, no. 4, p. 138, 1986, doi: 10.1520/CTR10335J.

[13] A. S. Chen and F. L. Matthews, "A review of multiaxial/biaxial loading tests for composite materials," *Composites*, vol. 24, no. 5, pp. 395–406, Jul. 1993, doi: 10.1016/0010-4361(93)90247-6.

[14] R. M. Christensen, "A Survey of and Evaluation Methodology for Fiber Composite Material Failure Theories," in *Mechanics for a New Mellennium*, H. Aref and J. W. Phillips, Eds., Dordrecht: Kluwer Academic Publishers, 2002, pp. 25–40. doi: 10.1007/0-306-46956-1_2.

[15] M. J. Hinton, A. S. Kaddour, and P. D. Soden, *Failure criteria in fibre reinforced polymer composites: the world-wide failure exercise*. Oxford: Elsevier, 2004.

[16] I. M. Daniel, "Failure of Composite Materials," *Strain*, vol. 43, no. 1, pp. 4–12, Feb. 2007, doi: 10.1111/j.1475-1305.2007.00302.x.

[17] H. Ku, H. Wang, N. Pattarachaiyakoop, and M. Trada, “A review on the tensile properties of natural fiber reinforced polymer composites,” *Composites Part B: Engineering*, vol. 42, no. 4, pp. 856–873, Jun. 2011, doi: 10.1016/j.compositesb.2011.01.010.
[18] A. Forghani, M. Shahbazi, N. Zobeiry, A. Poursartip, and R. Vaziri, “An overview of continuum damage models used to simulate intralaminar failure mechanisms in advanced composite materials,” in *Numerical Modelling of Failure in Advanced Composite Materials*, Elsevier, 2015, pp. 151–173. doi: 10.1016/B978-0-08-100332-9.00006-2.
[19] H. Fallahi, F. Taheri-Behrooz, and A. Asadi, “Nonlinear Mechanical Response of Polymer Matrix Composites: A Review,” *Polymer Reviews*, vol. 60, no. 1, pp. 42–85, Jan. 2020, doi: 10.1080/15583724.2019.1656236.
[20] L. Lecce, E. Monaco, and F. Ricci, “Laminates Progressive Failure Analysis: Recent Approaches Based on Finite Element Analysis Techniques,” in *Wiley Encyclopedia of Composites*, Hoboken, NJ, USA: John Wiley & Sons, Inc., 2012, p. weoc122. doi: 10.1002/9781118097298.weoc122.
[21] S. Abrate, J. F. Ferrero, and P. Navarro, “Cohesive zone models and impact damage predictions for composite structures,” *Meccanica*, vol. 50, no. 10, pp. 2587–2620, Oct. 2015, doi: 10.1007/s11012-015-0221-1.
[22] R. Bogenfeld, J. Kreikemeier, and T. Wille, “Review and benchmark study on the analysis of low-velocity impact on composite laminates,” *Engineering Failure Analysis*, vol. 86, pp. 72–99, Apr. 2018, doi: 10.1016/j.engfailanal.2017.12.019.
[23] M. Sadighi and R. Alderliesten, “Impact fatigue, multiple and repeated low-velocity impacts on FRP composites: A review,” *Composite Structures*, vol. 297, p. 115962, Oct. 2022, doi: 10.1016/j.compstruct.2022.115962.
[24] V. Krishnaraj, R. Zitoune, F. Collombet, and J. P. Davim, “Challenges in Drilling of Multi-Materials,” *MSF*, vol. 763, pp. 145–168, Jul. 2013, doi: 10.4028/www.scientific.net/MSF.763.145.
[25] A. M. Abrão, P. E. Faria, J. C. C. Rubio, P. Reis, and J. P. Davim, “Drilling of fiber reinforced plastics: A review,” *Journal of Materials Processing Technology*, vol. 186, no. 1–3, pp. 1–7, May 2007, doi: 10.1016/j.jmatprotec.2006.11.146.
[26] K. A. Calzada, “MODELING AND INTERPRETATION OF FIBER ORIENTATION-BASED FAILURE MECHANISMS IN MACHINING OF CARBON FIBER-REINFORCED COMPOSITES”.
[27] D. Liu, Y. Tang, and W. L. Cong, “A review of mechanical drilling for composite laminates,” *Composite Structures*, vol. 94, no. 4, pp. 1265–1279, Mar. 2012, doi: 10.1016/j.compstruct.2011.11.024.
[28] J. Xu, A. Mkaddem, and M. El Mansori, “Recent advances in drilling hybrid FRP/Ti composite: A state-of-the-art review,” *Composite Structures*, vol. 135, pp. 316–338, Jan. 2016, doi: 10.1016/j.compstruct.2015.09.028.
[29] P. Patel, V. Chaudhary, K. Patel, and P. Gohil, “Milling of Polymer Matrix Composites: A Review,” vol. 13, no. 10, 2018.
[30] I. Shyha and D. Huo, Eds., *Advances in Machining of Composite Materials: Conventional and Non-conventional Processes*. in Engineering Materials. Cham: Springer International Publishing, 2021. doi: 10.1007/978-3-030-71438-3.
[31] M. T. Hameed Sultan, A. I. Azmi, M. S. A. Majid, M. R. M. Jamir, and N. Saba, Eds., *Machining and Machinability of Fiber Reinforced Polymer Composites*. in Composites Science and Technology. Singapore: Springer Singapore, 2021. doi: 10.1007/978-981-33-4153-1.

[32] T. Gereke, O. Döbrich, M. Hübner, and C. Cherif, "Experimental and computational composite textile reinforcement forming: A review," *Composites Part A: Applied Science and Manufacturing*, vol. 46, pp. 1–10, Mar. 2013, doi: 10.1016/j.compositesa.2012.10.004.
[33] P. Boisse, N. Hamila, E. Guzman-Maldonado, A. Madeo, G. Hivet, and F. dell'Isola, "The bias-extension test for the analysis of in-plane shear properties of textile composite reinforcements and prepregs: a review," *Int J Mater Form*, vol. 10, no. 4, pp. 473–492, Aug. 2017, doi: 10.1007/s12289-016-1294-7.
[34] P. Boisse, J. Colmars, N. Hamila, N. Naouar, and Q. Steer, "Bending and wrinkling of composite fiber preforms and prepregs. A review and new developments in the draping simulations," *Composites Part B: Engineering*, vol. 141, pp. 234–249, May 2018, doi: 10.1016/j.compositesb.2017.12.061.
[35] P. Bussetta and N. Correia, "Numerical forming of continuous fibre reinforced composite material: A review," *Composites Part A: Applied Science and Manufacturing*, vol. 113, pp. 12–31, Oct. 2018, doi: 10.1016/j.compositesa.2018.07.010.
[36] Y. Gong *et al.*, "A comprehensive review of characterization and simulation methods for thermo-stamping of 2D woven fabric reinforced thermoplastics," *Composites Part B: Engineering*, vol. 203, p. 108462, Dec. 2020, doi: 10.1016/j.compositesb.2020.108462.
[37] B. Liang and P. Boisse, "A review of numerical analyses and experimental characterization methods for forming of textile reinforcements," *Chinese Journal of Aeronautics*, vol. 34, no. 8, pp. 143–163, Aug. 2021, doi: 10.1016/j.cja.2020.09.027.
[38] H. Chen, S. Li, J. Wang, and A. Ding, "A focused review on the thermo-stamping process and simulation progresses of continuous fibre reinforced thermoplastic composites," *Composites Part B: Engineering*, vol. 224, p. 109196, Nov. 2021, doi: 10.1016/j.compositesb.2021.109196.
[39] R. A. Brooks *et al.*, "A review on stamp forming of continuous fibre-reinforced thermoplastics," *International Journal of Lightweight Materials and Manufacture*, vol. 5, no. 3, pp. 411–430, Sep. 2022, doi: 10.1016/j.ijlmm.2022.05.001.
[40] J. Degrieck And and W. Van Paepegem, "Fatigue damage modeling of fibre-reinforced composite materials: Review," *Applied Mechanics Reviews*, vol. 54, no. 4, pp. 279–300, Jul. 2001, doi: 10.1115/1.1381395.
[41] S. David Müzel, E. P. Bonhin, N. M. Guimarães, and E. S. Guidi, "Application of the Finite Element Method in the Analysis of Composite Materials: A Review," *Polymers*, vol. 12, no. 4, p. 818, Apr. 2020, doi: 10.3390/polym12040818.
[42] S. Wicaksono and G. B. Chai, "A review of advances in fatigue and life prediction of fiber-reinforced composites," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 227, no. 3, pp. 179–195, Jul. 2013, doi: 10.1177/1464420712458201.
[43] J. A. Pascoe, R. C. Alderliesten, and R. Benedictus, "Methods for the prediction of fatigue delamination growth in composites and adhesive bonds – A critical review," *Engineering Fracture Mechanics*, vol. 112–113, pp. 72–96, Nov. 2013, doi: 10.1016/j.engfracmech.2013.10.003.
[44] S. Mortazavian and A. Fatemi, "Fatigue behavior and modeling of short fiber reinforced polymer composites: A literature review," *International Journal of Fatigue*, vol. 70, pp. 297–321, Jan. 2015, doi: 10.1016/j.ijfatigue.2014.10.005.
[45] R. D. B. Sevenois and W. Van Paepegem, "Fatigue Damage Modeling Techniques for Textile Composites: Review and Comparison With Unidirectional Composite Modeling Techniques," *Applied Mechanics Reviews*, vol. 67, no. 2, p. 020802, Mar. 2015, doi: 10.1115/1.4029691.

[46] I. M. Daniel, “Yield and failure criteria for composite materials under static and dynamic loading,” *Progress in Aerospace Sciences*, vol. 81, pp. 18–25, Feb. 2016, doi: 10.1016/j.paerosci.2015.11.003.
[47] M. Jawaid, M. Thariq, and N. Saba, Eds., *Failure analysis in biocomposites, fibre-reinforced composites and hybrid composites*. in Woodhead Publishing series in composites science and engineering. Duxford, United Kingdom ; Cambridge, MA: Woodhead Publishing, 2019.
[48] C. Rubiella, C. A. Hessabi, and A. S. Fallah, “State of the art in fatigue modelling of composite wind turbine blades,” *International Journal of Fatigue*, vol. 117, pp. 230–245, Dec. 2018, doi: 10.1016/j.ijfatigue.2018.07.031.
[49] A. Farazin and A. Khan, “An extensive study on strain dependence of glass fiber-reinforced polymer-based composites,” *The Journal of Strain Analysis for Engineering Design*, vol. 57, no. 6, pp. 411–432, Aug. 2022, doi: 10.1177/03093247211043714.
[50] A. Shalwan and B. F. Yousif, “In State of Art: Mechanical and tribological behaviour of polymeric composites based on natural fibres,” *Materials & Design*, vol. 48, pp. 14–24, Jun. 2013, doi: 10.1016/j.matdes.2012.07.014.
[51] M. Marian and S. Tremmel, “Current Trends and Applications of Machine Learning in Tribology—A Review,” *Lubricants*, vol. 9, no. 9, p. 86, Sep. 2021, doi: 10.3390/lubricants9090086.
[52] U. M. R. Paturi, S. Cheruku, and N. S. Reddy, “The Role of Artificial Neural Networks in Prediction of Mechanical and Tribological Properties of Composites—A Comprehensive Review,” *Arch Computat Methods Eng*, vol. 29, no. 5, pp. 3109–3149, Aug. 2022, doi: 10.1007/s11831-021-09691-7.
[53] A. T. Sose, S. Y. Joshi, L. K. Kunche, F. Wang, and S. A. Deshmukh, “A review of recent advances and applications of machine learning in tribology,” *Phys. Chem. Chem. Phys.*, vol. 25, no. 6, pp. 4408–4443, 2023, doi: 10.1039/D2CP03692D.