Benha Journal of Applied Sciences (BJAS) **print: ISSN 2356–9751**
Vol. (9) Issue (5) (2024), (105-112) **online: ISSN 2356–976x**
http://bjas.bu.edu.eg

Drilling Performance Evaluation of Innovative Waste Tire Rubber-Reinforced Polyester-Fiberglass Laminated Composites

M. Mosaad[1], T.S.Mahmoud[2], Ibrahim Mousa[2] and S.S. Mohamed[2]
[1]Manufacturing Engineering and Production Technology Dept., Modern Academy, Egypt
[2]Mechanical Engineering Dept, Shoubra Faculty of Engineering, Benha Univ., Egypt
E-mail: mohamed.atia18@feng.bu.edu.eg

Abstract

This research delves into the drilling behavior of a new generation of laminated composites. These composites are manufactured using a unique approach: recycled waste tire rubber particles are strategically embedded within a matrix composed of polyester and fiberglass. The core objective of this study is to meticulously assess how incorporating waste tire rubber particles impacts the performance of these composites during the drilling process. A comprehensive analysis is undertaken, meticulously examining factors that can significantly influence drilling, such as delamination, the forces exerted during drilling, and the overall quality of the drilled holes. Furthermore, the investigation explores the influence of various drilling parameters, including the size of the twist drill and the speed at which drilling is conducted. The findings of this research will illuminate the potential advantages and inherent challenges associated with utilizing waste tire rubber as a reinforcing element in polyester-fiberglass composites, specifically within the context of drilling. This work holds significant implications for the future of sustainable composite materials, aiming to achieve a balance between improved machinability and the promotion of recycled waste materials in construction and various manufacturing applications

Keywords: Hybrid polyester composite, rubber particles, delamination factor, drilling parameters.

1. Introduction

Polyester composites have become widely used in modern engineering due to their distinct combination of characteristics and adaptability. These materials are made up of a polyester resin matrix, which is reinforced with different fibers to improve mechanical performance [1]. High Strength-to-Weight Ratio: Polyester composites offer impressive strength and stiffness while maintaining a relatively low weight. This characteristic makes them ideal for applications where weight reduction is critical, such as in aerospace and automotive industries [2]. Design Flexibility: Polyester composites are easily molded into complicated shapes, enabling elaborate designs and increased functionality. Cost-Effectiveness: Compared to certain high-performance materials, polyester composites offer a less expensive choice while keeping desirable features [3].

The type of fiber reinforcing has a considerable influence on the composite's long-term qualities [4]. Common reinforcements include Glass fibers are the most popular choice due to their superior strength, low cost, and ease of manufacturing. Carbon fibers offer improved strength and rigidity, but at a higher cost. Natural fibers: Sustainable materials such as sisal and hemp provide eco-friendly alternatives that function well in specific applications [5]. Polyester composites' diversified qualities lead to a wide range of applications in a variety of industries. Transportation includes car body panels, boat hulls, and airplane components. Construction: Building panels, pipelines, and roofing materials Consumer goods include sporting equipment, electrical housings, and furniture components. Electrical engineering: Electrical insulators due to their high dielectric strength [6].

Waste tire disposal is a significant environmental issue. Landfills are at capacity, and burning tires emit hazardous pollutants. One interesting method is to incorporate waste tire particles (WTP) as reinforcement in polyester composites [7]. Waste tire disposal is a significant environmental issue. Landfills are at capacity, and burning tires emit hazardous pollutants. One interesting method is to incorporate waste tire particles (WTP) as reinforcement in polyester composites [8].

Waste tire particles show potential as a sustainable and cost-effective reinforcement for polyester composites. Addressing compatibility and dispersion issues is critical to maximizing their potential. Continued research and development can pave the path for more widespread use of WTP in a variety of composite applications.[9]

The quality of holes drilled in composite materials significantly impacts the success of bolted joints. These holes need to be precise and free of damage to ensure strong and accurate connections [10]. While non-traditional machining methods like electro-discharge machining, waterjet cutting, and laser drilling have been developed for composites, conventional drilling remains the most common technique despite its challenges [11].

A study by Thoppul et al. [12] investigated the influence of different bolt preload levels and external static and dynamic loads on the relaxation of bolt load in a carbon fiber-epoxy composite bolted joint. They observed a relaxation of 1.25% to 4.25% over 30 hours, depending on the initial preload and applied external loads. Their findings also showed that regardless of the external load magnitude, higher initial preload resulted in less bolt load relaxation.

Several studies have investigated the benefits of diamond-coated drilling tools for CFRP composites. A study by Iliescu et al employed electron microscopy and force measurements to compare tool wear between uncoated and diamond-coated carbide tools. Their findings indicated that diamond coating significantly extended tool life, by a factor of 10-12. Additionally, research by Gaugel et al.[13], supports this notion, demonstrating that diamond-coated tools offer a substantial increase in drill lifetime, particularly when delamination is the primary concern.

Several studies have shown that drilling parameters, drill geometry, and drill material all play a role in controlling delamination size in composite material [14]. Feed rate and thrust force, which are linked [14], [15], are often identified as the most influential factors on delamination [16], [17]. In contrast, cutting speed seems to have a greater impact on the quality of the hole surface itself However, there are conflicting reports, with some research not finding a direct correlation between thrust force and delamination in glass fiber composites.[18]

Mousa et al [19]. investigates a new laminated polyester composite incorporating waste tire rubber particles and glass fibers compared to traditional glass fiber-reinforced composites containing calcium carbonate (CaCO3). This novel composite has potential applications in the automotive and aviation industries. Flat laminated specimens were created for both the new and conventional composites using a hand layup technique. The results revealed an approximately 47% improvement for the novel composite, accompanied by an 8% reduction in density. Furthermore, the optimal drilling speed, minimizing delamination at both the front and back of the specimen, was determined to be around 1150 rpm.

A study by Durão et al. [20] investigated the influence of drill point geometry on drilling carbon fiber-reinforced epoxy laminates. They compared five different drill geometries for drills with a diameter of 6 mm. Their findings showed that both drill geometry and feed rate impact the thrust force generated during drilling. This allows for using higher feed rates when an appropriate drill geometry is chosen. The study also observed lower delamination with twist drills having a 120-degree point angle and step drills. Compared to the 120-degree twist drill, delamination increased by 6% for the dagger drill, 12% for the 85-degree twist drill, and 14% for the brad drill

Khashaba et al [21] study investigates the influence of drilling parameters on thrust force, torque, and delamination in glass fiber reinforced plastic (GFRP) composites. confirmed the established trend of increasing thrust force and torque with higher feed rates. It further provides quantitative data specific to the GFRP materials used. A positive correlation is found between fiber volume fraction and both thrust force and torque. In contrast, increasing cutting speed leads to a decrease in these forces. The study observes a correlation between increased feed rate and larger delamination size. Push-out delamination appears to be more prevalent than peel-up delamination. Cutting speed seems to have minimal impact on delamination size, achieving delamination-free drilling in chopped GFRPs with high fiber volume fraction remains an obstacle that warrants further investigation.

2. Methodology

2.1 Material

The Turkish supplier SUNPOL provided the unsaturated polyester resin with density 1.23 g/cm3. The recycled rubber particles were acquired from the Egyptian Company HOPPEC, with a mesh size of 40, their average density is 0.4 g/cm3. The fiberglass was provided by the Chinese-Egyptian business Jushi (product number E01). Its roll width is 1524 mm, and its area weight is 300 g/m2.

Preparation of composite

- **Layer 1 (28.3%):** Pure polyester resin forms the first layer with addition of hardener as recommended by the supplier, constituting 28.3% of the total composite volume.
- **Layer 2 (38.3%):** A mixture of rubber particles (10% of total volume) and polyester resin (28.3% of total volume) creates the second layer, contributing a combined 38.3% to the composite.
- **Layer 3 (33.3%):** The final layer consists of a fiberglass mat embedded in yet another layer of polyester resin, each accounting for 28.3% of the total composite volume.

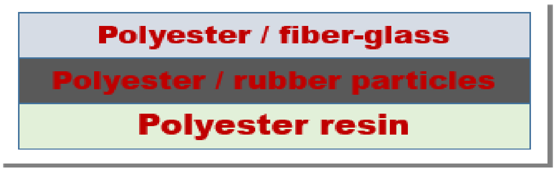

Fig. (1) Rubber polyester composite schematic of composite layers

The composite was prepared as follows [7], [22];

1. **Mold Creation:** A silicon rubber mold was created following the standard dimensions required for specimens.
2. **Polyester Resin Mixing:** The specified amount of polyester resin was weighed out based on the desired volume fraction. It was then degassed in a vacuum chamber for 5 minutes to remove trapped air bubbles.
3. **Hardener Addition and Degassing:** The hardener, following the supplier's recommendations, was added to the resin. The

mixture was further degassed in the vacuum chamber for 3 minutes.

4. **Casting and Curing:** The degassed mixture was poured into the prepared silicon rubber mold and left to solidify.
5. **Rubber Particles Addition:** Steps 2 and 3 (resin mixing and degassing) were repeated. For some specimens, rubber particles were incorporated into the resin mixture before pouring it into mold and curing as in step 4.
6. **Fiber Reinforcement:** fiberglass mat cut to the required dimensions was placed in the mold. Steps 2 and 3 (resin mixing and degassing) were then repeated to create fiber-reinforced composite laminate.
7. **Curing:** All molded specimens were left to cure in the mold for approximately 2 hours as shown in figure 2.

Fig. (2) Shown the molded specimen

2.2 Drilling process

A PMC-40, Bulgaria. benchtop drill with a maximum speed of 2400 rpm was used to create holes in the composite.

- **Drilling Speeds:** To identify the optimal speed for minimizing damage and delamination, two different speeds were tested: 535 and 2400 rpm.
- **Feed:** feed value was employed 0.22 mm/rev
- **Drilling Parameters:** two drill size of 4 and 8 mm made from high-speed steels (HSS) manufactured by Spanish company IZAR Cutting Tools were used for all the drilling operations.
- **Delamination Assessment**: The degree of delamination at each speed was evaluated using the delamination factor. This factor was measured twice per speed: once for the entry point (peel-up delamination) and once for the exit point (push-down delamination). The delamination factor is calculated by dividing the maximum diameter of the delaminated area by the nominal drill diameter. (Delamination factor = Maximum diameter of delamination / nominal diameter) [19], [21].
- **Drilling force**: the effect of variation of drilling parameters on resulted drilling force were measured by Dynamometer V-TECH DIGITAL FORCE INDICATOR MODEL 252.

3. Results and Discussion

3.1 Drilling parameters

The influence of rubber particles on the drilling response of polyester fiberglass composites is multifaceted the microstructure of specimen shown in figure 3. While they offer advantages such as reduced drill bit wear and improved chip formation, they also introduce challenges such as increased drilling force and potential for delamination. Careful consideration of particle type, concentration, and optimized drilling parameters is paramount to achieving a successful drilling process with these composites.[23]

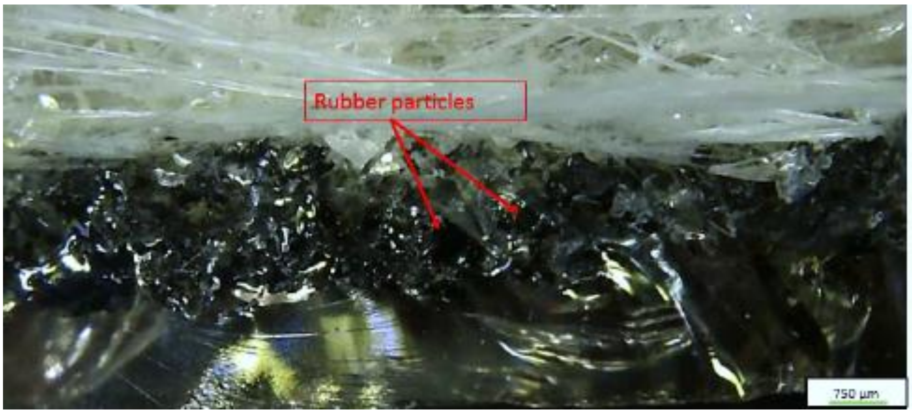

Figure 3 the microstructure of composite layers at 20X.

The combined effect of rubber particles and fiberglass on the drilling process depends on the specific goals. If minimizing drilling tool wear is a priority, a lower fiberglass content with a focus on optimizing rubber particle type and size might be preferable. However, if the focus is on achieving a stronger composite with good machinability, a balance between fiberglass reinforcement and rubber particle content needs to be established. [22], [24].

Figure 4 shows the variation of rotational speed and its effect on the resulted measured drilling force with twist drill size 4 mm and feed of 0.22 mm/rev. the polyester fiber composite with rubber particles shows much lower force at the lower speed while at higher speed the polyester resin gets a better behavior with lower drilling force but still close to the resulted one from the composite.

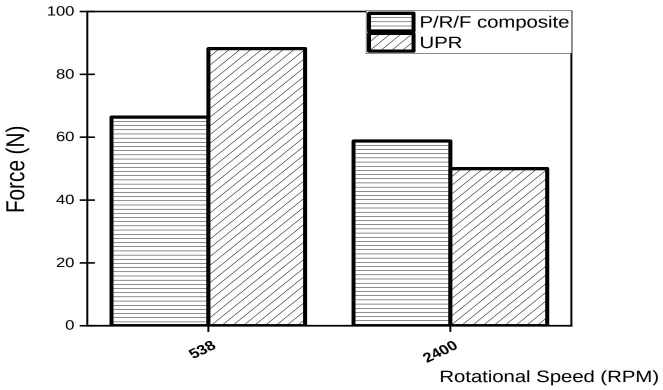

Fig. (4) The rotational speed vs the drilling force with twist drill size 4 mm

The drilled holes and the delamination show in figure 5 at this drilling condition the composite, Deep observation shows that push out delamination at the back side of the specimen is always greater than peel up one at the front side of the work piece, a superior behavior of the composite over the polyester resin with better hole circularity as revealed in figure 6.

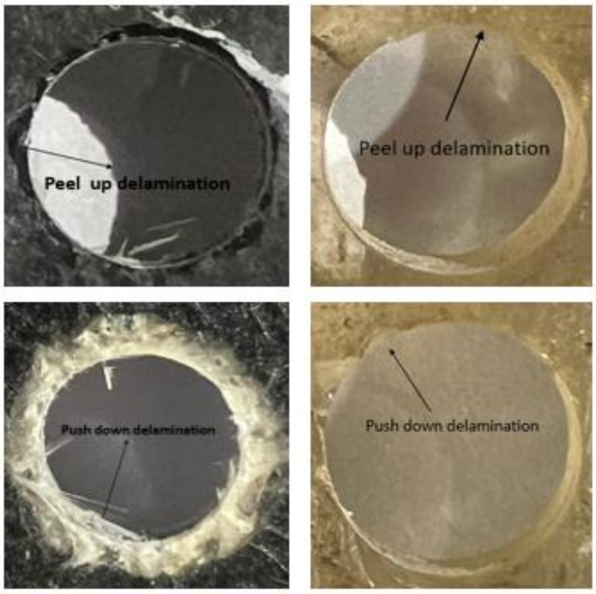

Fig. (5) Shows the drilled holes and deliminations

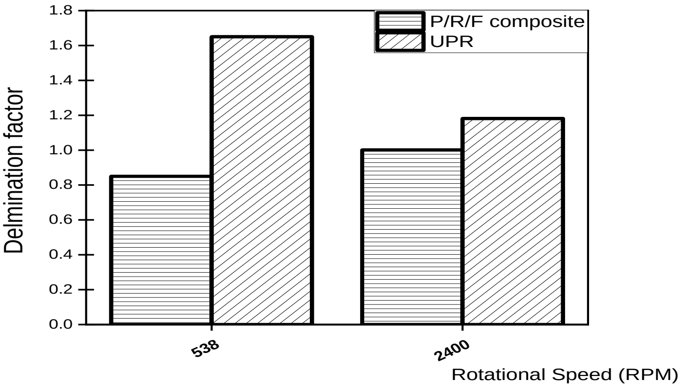

Fig. (6) Rotational speed vs delamination factor at twist drill 4mm.

The twist drill size changed from 4mm to 8mm, for more investigating of drilling parameter of the materials, increasing the twist drill size can create cleaner holes with less delamination around the edges, especially with the existence of rubber particles. However, they remove more material with more resulted drilling force, potentially weakening the overall structure as shown in the following figures [25].

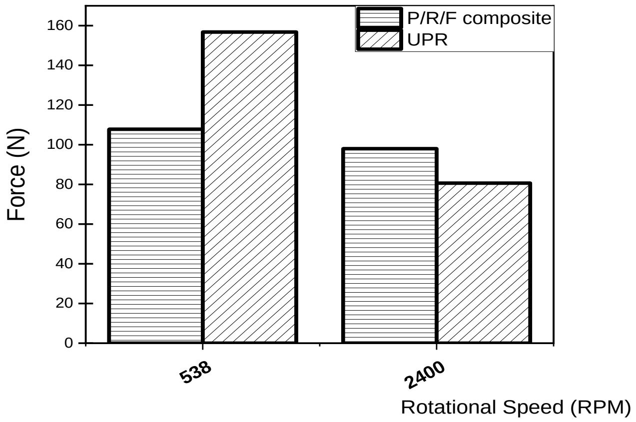

Fig. (6) The rotational speed vs the drilling force with twist drill size 8 mm

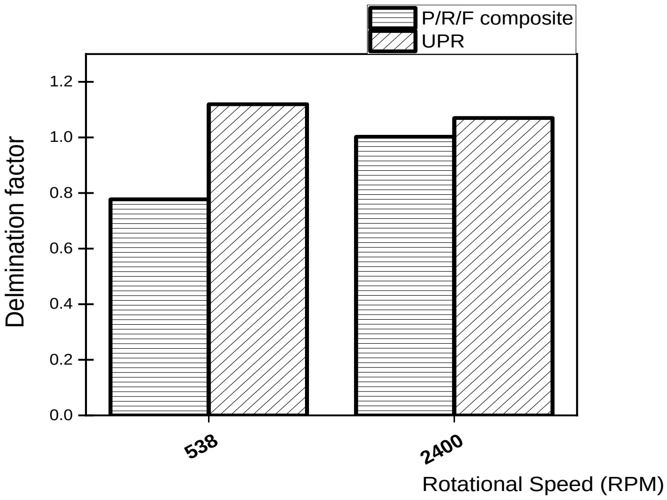

Fig. (7) Rotational speed vs delamination factor at twist drill 8mm

Figures 8 and 9 show that as the twist drill size increase the delamination factor decrease which lead to cleaner and better hole accuracy, especially at low speed with the polyester resin and a slight increase at high speed with composite that may be due to the fiber orientation and in contrast the drilling force increased with bigger twist drill size [26], although the drilling force decreased with the increase in rotational speed which agrees with [21].

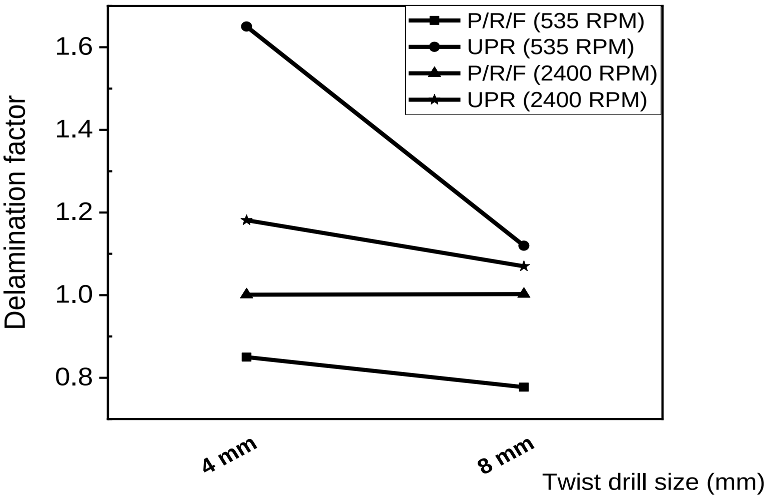

Fig. (8) The effect of twist drill size on delamination factor

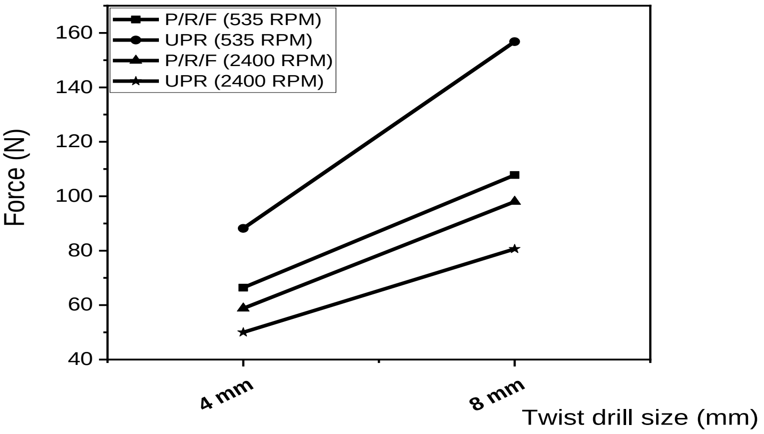

Fig. (9) The effect of twist drill size on the resulted drilling force

4. Conclusions

Evaluation of the drilling process of hybrid polyester fiberglass composite with the addition of rubber particles with comparison to the matrix material unsaturated polyester resin reveals the following

1. Effect of rotational speed on drilling force and delamination Increasing the rotational speed resulted with less drilling force and better hole circularity
2. Twist drill size effect on delamination larger drills generally lead to reduced delamination and cleaner, more accurate holes, especially at low drilling speeds with polyester resin composites.
   At high speeds, the benefit of larger drills on delamination for composite materials might be slightly less pronounced, potentially due to fiber orientation.
3. Twist drill size effect on the resulted drilling Force Larger drills require a higher drilling force due to the increased removal rate Overall, the composite showed a better drilling characteristics than the polyester resin

References

[1] M. Y. Mahmoud Zaghloul, M. M. Yousry Zaghloul, and M. M. Yousry Zaghloul, “Developments in polyester composite materials – An in-depth review on natural fibres and nano fillers,” *Compos. Struct.*, vol. 278, p. 114698, Dec. 2021, doi: 10.1016/J.COMPSTRUCT.2021.114698.

[2] S. H. Kamarudin, Mohd Basri, Mohd Salahuddin Rayung, Marwah Abu,Falah Ahmad, So’bah Norizan, Mohd Nurazzi Osman, Syaiful Sarifuddin, Norshahida Desa, Mohd Shaiful Zaidi Mat Abdullah, Ummi Hani Mohamed Amin Tawakkal, Intan Syafinaz Abdullah, Luqman Chuah., “A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications,” *Polymers (Basel).*, vol. 14, no. 17, pp. 1–36, 2022, doi: 10.3390/polym14173698.

[3] H. Mahfuz, V. K. Rangari, M. S. Islam, and S. Jeelani, “Fabrication, synthesis and mechanical characterization of nanoparticles infused polyurethane foams,” *Compos. Part A-applied Sci. Manuf.*, vol. 35, no. 4, pp. 453–460, Apr. 2004, doi: 10.1016/J.COMPOSITESA.2003.10.009.

[4] S. M. Harle, “Durability and long-term performance of fiber reinforced polymer (FRP) composites: A review,” *Structures*, vol. 60, p. 105881, Feb. 2024, doi: 10.1016/J.ISTRUC.2024.105881.

[5] I. Elfaleh, Abbassi, Fethi Habibi, Mohamed Ahmad, Furqan Guedri, Mohamed Nasri, Mondher Garnier, Christian., “A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials,” *Results Eng.*, vol. 19, p. 101271, Sep. 2023, doi: 10.1016/J.RINENG.2023.101271.

[6] M. Bhong Khan, Tasneem K.H. Devade, Kiran Vijay Krishna, B.Sura, Sreekanth Eftikhaar, H.K. Pal Thethi, H.Gupta, Nakul., “Review of composite materials and applications,” *Mater. Today Proc.*, Oct. 2023, doi: 10.1016/J.MATPR.2023.10.026.

[7] A. S.Abdel-Wanees, B. Hany Mousa, I. M.Ibrahim, and T. S.Mahmoud, “Assessment Study on the Mechanical Behavior of Polyester – Fiber Composite Laminates Filled with Waste Tire Rubber Particles,” *Benha J. Appl. Sci.*, vol. 7, no. 4, pp. 21–23, 2022, doi: 10.21608/bjas.2022.251248.

[8] A. M. Moasas, Muhammad Nasir, Khan Kaffayatullah, Ahmad Waqas, Mohammed Najeeb, Deifalla Ahmed Farouk, Ahmad Ayaz, “A worldwide development in the accumulation of waste tires and its utilization in concrete as a sustainable construction material: A review,” *Case Stud. Constr. Mater.*, vol. 17, p. e01677, Dec. 2022, doi: 10.1016/J.CSCM.2022.E01677.

[9] D. A. Singaravel, P. Veerapandian, S. Rajendran, and R. Dhairiyasamy, "Enhancing high-performance concrete sustainability: integration of waste tire rubber for innovation," *Sci. Reports 2024 141*, vol. 14, no. 1, pp. 1–17, Feb. 2024, doi: 10.1038/s41598-024-55485-9.

[10] D. F. Liu, Y. J. Tang, and W. L. Cong, "A review of mechanical drilling for composite laminates," *Compos. Struct.*, vol. 94, no. 4, pp. 1265–1279, Mar. 2012, doi: 10.1016/J.COMPSTRUCT.2011.11.024.

[11] L. Sorrentino, L. Esposito, and C. Bellini, "A new methodology to evaluate the influence of curing overheating on the mechanical properties of thick FRP laminates," *Compos. Part B Eng.*, vol. 109, pp. 187–196, Jan. 2017, doi: 10.1016/J.COMPOSITESB.2016.10.064.

[12] S. D. Thoppul, R. F. Gibson, and R. A. Ibrahim, "Phenomenological modeling and numerical simulation of relaxation in bolted composite joints," *J. Compos. Mater.*, vol. 42, no. 17, pp. 1709–1729, Sep. 2008, doi: 10.1177/0021998308092544.

[13] Simon Gaugel, Prithvi Sripathy, Andreas Haeger, Dieter Meinhard, Timo Bernthaler, Fabian Lissek, Michael Kaufeld, Volker Knoblauch, Gerhard Schneider, "A comparative study on tool wear and laminate damage in drilling of carbon-fiber reinforced polymers (CFRP)," *Compos. Struct.*, vol. 155, pp. 173–183, Nov. 2016, doi: 10.1016/J.COMPSTRUCT.2016.08.004.

[14] U. A. Khashaba, I. A. El-Sonbaty, A. I. Selmy, and A. A. Megahed, "Machinability analysis in drilling woven GFR/epoxy composites: Part I – Effect of machining parameters," *Compos. Part A Appl. Sci. Manuf.*, vol. 41, no. 3, pp. 391–400, Mar. 2010, doi: 10.1016/J.COMPOSITESA.2009.11.006.

[15] H. Hocheng, C. C. Tsao, C. S. Liu, and H. A. Chen, "Reducing drilling-induced delamination in composite tube by magnetic colloid back-up," *CIRP Ann.*, vol. 63, no. 1, pp. 85–88, Jan. 2014, doi: 10.1016/J.CIRP.2014.03.070.

[16] J. P. Davim, P. Reis, and C. C. António, "Drilling fiber reinforced plastics (FRPs) manufactured by hand lay-up: Influence of matrix (Viapal VHP 9731 and ATLAC 382-05)," *J. Mater. Process. Technol.*, vol. 155–156, no. 1–3, pp. 1828–1833, Nov. 2004, doi: 10.1016/J.JMATPROTEC.2004.04.173.

[17] Vijayan Krishnaraj, A. Prabukarthi, Arun Ramanathan, N.Elanghovan, M. Senthil Kumar, Redouane Zitoune, J.P. Davim, "Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates," *Compos. Part B Eng.*, vol. 43, no. 4, pp. 1791–1799, Jun. 2012, doi: 10.1016/J.COMPOSITESB.2012.01.007.

[18] A. M. Abrão, J. C. C. Rubio, P. E. Faria, and J. P. Davim, "The effect of cutting tool geometry on thrust force and delamination when drilling glass fibre reinforced plastic composite," *Mater. Des.*, vol. 29, no. 2, pp. 508–513, Jan. 2008, doi: 10.1016/J.MATDES.2007.01.016.

[19] B. H. Mousa, N. A. Azab, G. Bassioni, and M. H. Abdellatif, "Assessment of the Damage Resulting from Drilling Holes in Waste Tire Rubber Polyester Composite Laminates," *Waste and Biomass Valorization*, vol. 12, no. 7, pp. 4069–4080, 2021, doi: 10.1007/s12649-020-01291-z.

[20] L. M. P. Durão, D. J. S. Gonçalves, J. M. R. S. Tavares, V. H. C. de Albuquerque, A. Aguiar Vieira, and A. Torres Marques, "Drilling tool geometry evaluation for reinforced composite laminates," *Compos. Struct.*, vol. 92, no. 7, pp. 1545–1550, Jun. 2010, doi: 10.1016/J.COMPSTRUCT.2009.10.035.

[21] U. A. Khashaba, M. A. Seif, and M. A. Elhamid, "Drilling analysis of chopped composites," *Compos. Part A Appl. Sci. Manuf.*, vol. 38, no. 1, pp. 61–70, Jan. 2007, doi: 10.1016/J.COMPOSITESA.2006.01.020.

[22] M. Mosaad, T. S.Mahmoud, B. Hany Mousa, I. Mousa, and S. S. Mohamed, "Investigation On the Effect of Variation of Drilling Parameters On the Delamination Factor in Waste Tire Rubber Polyester Composite Laminates," *Benha J. Appl. Sci.*, vol. 7, no. 4, pp. 249–252, 2022, doi: 10.21608/bjas.2022.260500.

[23] T. V. Rajamurugan, C. Rajaganapathy, S. P. Jani, C. S. Gurram, H. L. Allasi, and S. Z. Damtew, "Analysis of Drilling of Coir Fiber-Reinforced Polyester Composites Using Multifaceted Drill Bit," *Adv. Mater. Sci. Eng.*, vol. 2022, 2022, doi: 10.1155/2022/9481566.

[24] S. C. Gutiérrez, M. D. Meseguer, A. Muñoz-Sánchez, and N. Feito, "Study of the Influence of Tool Wear of Two Drill Bits Manufactured with Different Coating Processes in Drilling Carbon/Glass Fiber Hybrid Composite Bounded with Epoxy Polymer," *Coatings*, vol. 13, no. 8, Aug. 2023, doi: 10.3390/COATINGS13081440.

[25] B. Mclean, A. Page, G. Han, and X. Hu, "Repair of Small-Area Delamination in Carbon Fiber-Reinforced Polymer through Small Drilled Hole and Carbon Nanotubes-Reinforced Resin Pre-Coating Technique," *Inorganics 2023, Vol. 11, Page 454*, vol. 11, no. 12, p. 454, Nov. 2023, doi: 10.3390/INORGANICS11120454.

[26] Praveenkumara Jagadeesh, Sanjay Mavinkere Rangappa, Indran Suyambulingam, Suchart Siengchin, Madhu Puttegowda, Joseph Selvi Binoj, Sergey Gorbatyuk, Anish Khan,

Mrityunjay Doddamani, Vincenzo Fiore, Marta María Moure Cuadrado, "Drilling characteristics and properties analysis of fiber reinforced polymer composites: A comprehensive review," *Heliyon*, vol. 9, no. 3, p. e14428, Mar. 2023, doi: 10.1016/J.HELIYON.2023.E14428.