Investigation of the High Velocity Impact Test on the Curved Glass Fiber Reinforced Plastic (GFRP) Composites Using Explicit Dynamics Analysis

Batool Mardan Faisal^a, K. A. Abed^b, Ayad Ali Mohammed^c, Emad Kamil Hussein^d, Hussein Kadhim Sharaf^{e,f,*}, Thiago Santos^g, Caroliny Santos^g

^a Mechanical Engineering Department, College of Engineering, Wasit University, Wasit, Iraq ^b University of Anbar, College of Engineering: Ramadi City, Al Anbar, Iraq ^c Al-Furat Al-Awsat Technical University, Al-Mussaib Technical College, Babil, Iraq ^d Mechanical Power Engineering Department, Mussaib Technical College, Al Furat Al Awsat Technical University, Babil, Iraq ^e AL-Muqdad College of Education, University of diyala, Diyala, Iraq ^f University of Bilad al rafidain, Baquba, Diyala Governorate, Iraq ^g Technology center, Federal University of Rio Grande do Norte, Av. Prof. Sen. Salgado Filho, 3000, Natal, Rio Grande do Norte, Brazil

Corresponding author: *hk.sharaf92@gmail.com

Abstract—In this study, investigation of the high-Velocity Impact test on the curved glass fiber reinforced plastic (GFRP) composites using explicit dynamics analysis has been performed using FEM. Four types of energy were examined: internal energy, kinetic energy, contact energy, and hourglass energy. The investigation revealed that the most significant variation occurred in the internal energy, reaching a peak value of 1.0e-3. Deformation due to impacted forces was considered accordingly. Three forces were considered accordingly: 1,2,3 kn. Based on the numerical analysis, the maximum deformation was reached 76 mm. Von Mises stress due to the applied load was considered as well. The von Mises stresses using explicit dynamic tools in analysis software. Three loads were considered for the general inspections till 3 KN. The numerical results proved that the maximum stress reached 22 MPa. This substantial change is primarily due to the alterations in the material's morphology, indicating how the material's internal structure responded to the applied conditions. Kinetic energy, which relates to the motion of the material, and contact energy, which pertains to the interactions at the material's surfaces, were also analyzed. However, these energies did not exhibit as pronounced changes as the internal energy.

Keywords—Curved glass fiber reinforced plastic; explicit dynamics; ansys; FEM.

Manuscript received 11 Oct. 2023; revised 27 Jan. 2024; accepted 12 Mar. 2024. Date of publication 31 Dec. 2024. IJASEIT is licensed under a Creative Commons Attribution-Share Alike 4.0 International License.



I. INTRODUCTION

Since this event has taken place, it is of the utmost importance that research be carried out to explore the impact behavior of these materials when they are subjected to items that come from the outside [1], [2]. Some different methods, including theoretical, experimental, and numerical simulation, have been utilized by researchers to investigate the dynamic effect of composite laminates [3]. Because of these methods, noteworthy conclusions have been discovered [4]. There are some common damage features that are found, particularly in the region of the impact site [5], [6]. These characteristics include indentations. matrix cracks. delamination. and fiber fractures. The mechanical

characteristics of the laminates may be significantly altered due to these faults, which is a possibility [7]. For composite laminates to be classified, Olsson described their impact responses according to the mass ratio of the impactor to the target plate. This allowed for the composite laminates to be classified. An analogy may be drawn between these enormous hits, which have a mass ratio that is more than two, and quasistatic loading, which takes place when the inertial force that is exerted by the plate is insignificant, and the contact force and plate deflection are in sync with one another [8], [9]. At the opposite end of the spectrum, low-mass strikes are characterized by a mass ratio that is lower than one-fifth. Because of these impacts trigger wave-related local responses and high-order vibrations, eventually resulting in asynchronous deflection changes and asymmetrical contact force curves [10], [11].

Composite materials, recognized for their high specific strength and modulus in the fiber direction and their better strength-to-weight ratios than conventional materials, are rapidly being utilized in the building, transportation, and aerospace industries [12]. As a result of these characteristics, composite materials are becoming increasingly popular. The recent completion of dynamic testing of the prototype maglev train that travels 600 kilometers per hour by CRRC Qingdao Sifang Co. has brought to light the growing relevance of lightweight composites in manufacturing future rail transit vehicles [13][14]. On the other hand, high-speed trains and airplanes are prone to be attacked by foreign objects, such as hailstones and bird strikes, which can considerably weaken the structural integrity of these vehicles. This can be a serious risk to the safety of passengers and crew. Therefore, it is of the highest significance to understand composite materials' dynamic and high-velocity impact reactions[15] [16].

It is rare for buildings and modern engineering parts to experience only steady forces. Most parts of buildings and structures experience loads that change regularly or irregularly over time. Because of this, design analysts pay attention to the problems in materials when subjected to repeated stress. In parts of a structure that experience repeated forces, there are regular or irregular stress patterns depending on the type of load. These stresses often lead to the part breaking down over time due to fatigue. After World War II, improvements in glue technology led to a big rise in the use of glued joints. Because of this, studying how adhesive joints wear out has become an important area of research. After the 1970s, the use of glue joints in the aerospace industry grew, making it even more essential to study fatigue. Fatigue happens because of various flaws and material breaks, which can lead to damage [17]. So, there is always a chance that the adhesive joints can bond at the area where they connect or within the adhesive layer itself. These hidden flaws can cause wear and tear over time when things are repeatedly pushed and pulled. So, besides figuring out how strong adhesive joints are when there is a steady load, it's also essential to understand how they perform when there are repeated loads. Mechanical parts often face changing and repeated forces [18]. Parts that go through repeated stress over time can break down from fatigue, even if the stress levels are lower than they can handle when not moving. It is essential to find out how strong the adhesive joints are when they are tired or worn out [19].

Recently, some studies have looked at how different tiny particles, especially those included in epoxy glues, affect the strength of the glue joints. When we look at these studies, we can see that tiny particles significantly impact the strength of the glued connections. These studies show that tiny particles improve the adhesive, even when only a small amount is used. Nanoparticles help adhesives in several ways [20]. They make adhesives better at conducting heat and electricity, and they also improve their strength against things like weather. Moreover, nanoparticles allow adhesives to absorb more water and help them last longer [21]. The authors [22] and [23] studied how adding tiny particles to epoxy glue affects the strength of the glue joints. The study used carbon fiber, epoxy resin layers, and 6061-T6 aluminum layers to stick together. Dexter Hysol EA 9330 epoxy was used as glue, and carbon nanotubes (CNT) and aluminum nano-powder (ANP) were used as tiny particles [24]. The results showed that changing the number of nanoparticles mixed into the epoxy glue significantly affects how well it sticks and holds up under stress. The results also showed that adding more nanoparticles than a certain amount in the adhesive weakens the connection strength [25]. Other researchers [26] have examined how different tiny particles and rough surfaces affect how well epoxy glue sticks to a surface. The study used steel sheets to stick together with Pattex® Kraft-Mix adhesive (from Henkel Adhesives Ltd.), a two-part glue. The tiny particles used as additives were nano-Al2O3, nano-CaCO3, and nano-SiO2. The pull-off adhesion tests showed that nano-Al2O3, one of the three types of nanoparticles, had the most significant impact on how strong the adhesion was. Experts have conducted a detailed analysis of the high-speed impact behavior of composites [27][28]. This investigation was carried out using a mix of simulations and direct testing. Experiments are the most efficient way to research the mechanical characteristics of continuous fiber-reinforced composites [29]. This is because of the anisotropic nature of these composites, which makes studies of their mechanical properties difficult to conduct .

After comparing the impact testing results with the damage evolution models that the authors had created, the authors concluded that the damage evolution models were highly accurate for the various failure modes that may occur in composites. Within high-speed collisions, the authors in [30] have identified three potential methods in which fiberreinforced laminates can absorb impact energy. Local fragmentation, linear momentum transfer, and tensile fiber breaking are the names given to these three techniques. More studies have been done on the failure and damage behavior of curved FRP composite plates and advanced structural sections when they are subjected to impact stresses [31]. As a result, the high-velocity impact test on the curved glass fiber reinforced plastic (GFRP) composites was carried out in this work. The approach that was used was to use explicit dynamics analysis.

II. MATERIALS AND METHOD

A. Geometry and Meshing

Geometry is divided into two distinct components. Punchers are the initial component, consisting of a square shell made of solid material. The other component is the target component, constructed from composite layers of GFRB woven plate, as shown in Figure 1. The geometry has been transferred to the explicated dynamics so that it may be aligned with the dynamics. To accurately simulate the enormous deflection, the mesh approach has been chosen from the sweep category. One of the nonlinear elements that has been selected is the mesh element. The tool for sizing is utilized to ensure that all bodies are established as soft materials for the target plate, with a size of 5 millimeters being the element size. It has also been decided that a size tool will be used for the puncher, and it will have the same element but be in the hard category. 14000 elements have been achieved as the total element for the geometry



Fig. 1 Meshed model of the GFRB Plate

B. Primary Boundary Conditions

According to the data presented in Figure 2, the curved glass fiber reinforced plastic (GFRP) composites investigated in this work were performed numerically. Four fixed supports were employed in every direction, and the force was one hundred newtons with a high-velocity impact.



Fig. 2 Boundary Conditions

C. Critical Convergence Analysis

It is crucially important that the total deformation indicator be utilized to carry out the convergence analysis for the current study on convergence. It began with the initial effort at 3.512e-3 mm and then significantly expanded from there [31]. It has been established that the second solution is present at 3.59e-3 mm. Based on the findings of the critical analysis of the existing procedure, the current case has been converged at the second solution. Figure 3 illustrates the explanation of the convergence process described above.



Fig. 3 Critical convergence test

D. FEM set up

Figure 4 This was done to maximize the effectiveness of the composites. A study of the high-speed impact test was performed with the help of the impact analysis feature found in the Ansys program. The RTM technique was used to produce the curved GFRP plates, and commercially available prepreg layers were utilized in manufacturing [32]. The CRRC Qingdao Sifang provided these layers. Rolling around When cutting woven fabric laminates with a stacking sequence of 12.

E. Material properties

In this context, the rigid material model is employed to model the projectile, as it is stiffer than the target plate. To ensure accurate contact modeling, the projectile is assigned the material properties of steel, which include a mass of 106.8 grams, a Young's modulus of 210 GPa, and a Poisson's ratio of 0.32.

III. RESULTS AND DISCUSSION

A. Investigation of Total Deformation and Stresses due to high-speed Impact

The total deformation curve has been calculated using numerical simulation based on the static structural tool in Ansys software, as shown in Figure 3. Applied forces have been subjected to the component's procedure applied in the X direction. Four values: 1, 2, and 3KN, as shown in Figure 4. The maximum stresses at the joint reached 81 mm at force 3.15 KN. The minimum von Mises stress was recorded at a minimum applied load 55 mm, where it reached 30 mm.



Fig. 4 Load-displacement status

Figure 5 shows the graphical effect of the applied force on the bounded plates. The simulation results show that the bounded area is simulated to the rest of the plate, and the maximum effect of the force begins at the end of the plate. The maximum elongation along the plate is 81 mm for the maximum applied load. The simulation process was undertaken with a static structural tool. total deformation has been considered a leading indicator. For this investigation, a load of 3.15 kilonewtons was applied to the alloy plate in two different directions while maintaining the same elevation. There was a maximum deformation of 7.0e-7 meters when this load was used, a graphical representation that illustrates the precise location of the maximum deformation. At the beginning of the fractures, the concertation of the deformation can be perceived.



B. The Analysis of Strain Energy

In this study, an alloy plate was subjected to a 3.15 kilonewton force in two directions with the same height maintained. This system was built to observe the material's behavior under stress. The maximum deformation energy recorded was 0.0029 meters, indicating that the material was significantly distorted due to the applied force. Figure 4 visually represents the deformation and pinpoints the location of the most significant distortion. This area is crucial because it shows the beginning of fractures and has the highest deformation concentration, making it easy to spot. An indepth familiarity with this concentration is critical for predicting the breakdown locations and increasing the material's durability.





Fig. 6 Investigation of Strain energy

C. Residual Stress (Von Mises Stresses)

Von Mises stresses have been calculated using the static structural tool in ANSYS software. The Von Mises stress is the main indicator of the residual stresses in the contacted zone. Since the model is symmetrical, the residual stresses at both sides of the substance material are the same. The stresses have been calculated using multiple applied forces. Applied forces have been subjected to the component's procedure, which is applied concerning the X direction. four values were applied: 1, 2, and 3 KN, as shown in Figure 7. The maximum stresses at the point reached 22 MPa at force 3.15 KN. The minimum von Mises stress was recorded at minimum applied load 1 KN where it reached 8 MPa



Fig. 7 Residual stress

D. Energy-time Analysis

Everything from internal to kinetic to contact to hourglass energies was considered in this study. The experiment's findings revealed that the internal energy changed significantly, peaking around 1.0e-3. Because it demonstrates how the material's internal structure responded to the applied conditions, its morphology is primarily responsible for this notable change. We also looked at contact energy, associated with interactions at the material's surfaces, and kinetic energy, associated with the material's mobility. However, compared to these other energies, changes in the internal energy were noticeably more pronounced. Hourglass energy, a prevalent cause of numerical aberrations in finite element analysis, was left out of the comprehensive study because of its insignificance. This exclusion isolates the energy changes that significantly impact the material's behavior. To further understand the distribution and magnitude of the energy fluctuations in the material, we refer to Figure 8, which displays all of the energy types and their variations.



Fig. 8 Energy analysis

IV. CONCLUSION

In conclusion, using the explicit dynamics analysis that is available in FEM, the high-velocity impact test that was performed on the curved GFRP composites was ultimately investigated. Internal energy, kinetic energy, contact energy, and hourglass energy were the four forms of energy that were investigated. It was discovered that internal energy was the most variable since it fluctuated the most and reached its highest point at 1.0e-3. This discernible change is primarily attributable to alterations in the material's morphology, which indicate the reaction of the material's internal structure to the applied conditions. Other factors that were considered were kinetic energy, which refers to the mobility of the material, and contact energy, which is concerned with the interactions that occur at the surfaces of the material. However, the energy contained therein did not alter nearly as much as these energies did.

ACKNOWLEDGMENT

Any grant did not fund this research

REFERENCES

- C. Yang, Y. Gao, W. Guo, Y. Yang, P. Xu, and M. S. Alqahtani, "High-velocity impact behaviour of curved GFRP composites for rail vehicles: Experimental and numerical study," *Polymer Testing*, vol. 116, p. 107774, Dec. 2022, doi:10.1016/j.polymertesting.2022.107774.
- [2] F. Chen, Y. Peng, X. Chen, K. Wang, Z. Liu, and C. Chen, "Investigation of the Ballistic Performance of GFRP Laminate under 150 m/s High-Velocity Impact: Simulation and Experiment," *Polymers*, vol. 13, no. 4, p. 604, Feb. 2021, doi:10.3390/polym13040604.
- [3] C. Stephen, B. Shivamurthy, A.-H. I. Mourad, and R. Selvam, "High-velocity impact behavior of hybrid fiber-reinforced epoxy composites," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 43, no. 9, Aug. 2021, doi: 10.1007/s40430-021-03139-6.
- [4] S.-H. Xin and H. M. Wen, "Numerical study on the perforation of fiber reinforced plastic laminates struck by high velocity projectiles," *The Journal of Strain Analysis for Engineering Design*, vol. 47, no. 7, pp. 513–523, Aug. 2012, doi: 10.1177/0309324712454650.
- [5] I. K. Giannopoulos, M. Yasaee, and N. Maropakis, "Ballistic Impact and Virtual Testing of Woven FRP Laminates," *Journal of Composites Science*, vol. 5, no. 5, p. 115, Apr. 2021, doi: 10.3390/jcs5050115.
- [6] E. Sevkat, B. Liaw, F. Delale, and B. B. Raju, "A combined experimental and numerical approach to study ballistic impact response of S2-glass fiber/toughened epoxy composite beams," *Composites Science and Technology*, vol. 69, no. 7–8, pp. 965–982, Jun. 2009, doi: 10.1016/j.compscitech.2009.01.001.
- [7] M. V. Mousavi and H. Khoramishad, "Investigation of energy absorption in hybridized fiber-reinforced polymer composites under high-velocity impact loading," *International Journal of Impact Engineering*, vol. 146, p. 103692, Dec. 2020, doi: 10.1016/j.ijimpeng.2020.103692.
- [8] H. Khaledi and Y. Rostamiyan, "High-speed impact analysis of reinforced GFRP sandwich structure with lattice core using experimental and finite element methods," *Plastics, Rubber and Composites*, vol. 52, no. 3, pp. 171–185, Jul. 2022, doi:10.1080/14658011.2022.2103621.
- [9] O. T. Topac, B. Gozluklu, E. Gurses, and D. Coker, "Experimental and computational study of the damage process in CFRP composite beams under low-velocity impact," *Composites Part A: Applied Science and Manufacturing*, vol. 92, pp. 167–182, Jan. 2017, doi:10.1016/j.compositesa.2016.06.023.
- [10] P. Wilson, A. Ratner, G. Stocker, F. Syred, K. Kirwan, and S. Coles, "Interlayer Hybridization of Virgin Carbon, Recycled Carbon and Natural Fiber Laminates," *Materials*, vol. 13, no. 21, p. 4955, Nov. 2020, doi: 10.3390/ma13214955.

- [11] K. Venkatesan, S. Rajaram, I. Jenish, and G. B. Bhaskar, "Fatigue and creep behavior of abaca-sisal natural fiber-reinforced polymeric composites," *Biomass Conversion and Biorefinery*, vol. 14, no. 16, pp. 19961–19972, May 2023, doi: 10.1007/s13399-023-04295-6.
- [12] M. Jakob et al., "The strength and stiffness of oriented wood and cellulose-fibre materials: A review," *Progress in Materials Science*, vol. 125, p. 100916, Apr. 2022, doi: 10.1016/j.pmatsci.2021.100916.
- [13] Z. Zhang, S. Ding, C. Zhao, and X. Liang, "Development progress of China's 600 km/h high-speed magnetic levitation train," *Frontiers of Engineering Management*, vol. 9, no. 3, pp. 509–515, Jul. 2022, doi:10.1007/s42524-022-0199-z.
- [14] H. Li, J. Shi, X. Li, J. Zhang, and Y. Chen, "Current status and reflection on the development of high-speed maglev transportation," *Railway Sciences*, vol. 2, no. 3, pp. 327–335, Oct. 2023, doi:10.1108/rs-07-2023-0024.
- [15] S. N. A. Safri, M. T. H. Sultan, N. Yidris, and F. Mustapha, "Low velocity and high velocity impact test on composite materials—A review," *International Journal of Engineering Science*, vol. 3, pp. 50– 60, 2014.
- [16] Y. Li et al., "A review of high-velocity impact on fiber-reinforced textile composites: Potential for aero engine applications," *International Journal of Mechanical System Dynamics*, vol. 2, no. 1, pp. 50–64, Mar. 2022, doi: 10.1002/msd2.12033.
 [17] P. Foti, N. Razavi, A. Fatemi, and F. Berto, "Multiaxial fatigue of
- [17] P. Foti, N. Razavi, A. Fatemi, and F. Berto, "Multiaxial fatigue of additively manufactured metallic components: A review of the failure mechanisms and fatigue life prediction methodologies," *Progress in Materials Science*, vol. 137, p. 101126, Aug. 2023, doi:10.1016/j.pmatsci.2023.101126.
- [18] W. Abd-Elaziem et al., "Influence of nanoparticles addition on the fatigue failure behavior of metal matrix composites: Comprehensive review," *Engineering Failure Analysis*, vol. 155, p. 107751, Jan. 2024, doi: 10.1016/j.engfailanal.2023.107751.
- [19] A. Akhavan-Safar, G. Eisaabadi Bozchaloei, S. Jalali, R. Beygi, M. R. Ayatollahi, and L. F. M. da Silva, "Impact Fatigue Life of Adhesively Bonded Composite-Steel Joints Enhanced with the Bi-Adhesive Technique," *Materials*, vol. 16, no. 1, p. 419, Jan. 2023, doi:10.3390/ma16010419.
- [20] F. Ferruti et al., "Recombinatorial approach for the formation of surface-functionalised alkaline-stable lignin nanoparticles and adhesives," *Green Chemistry*, vol. 25, no. 2, pp. 639–649, 2023, doi:10.1039/d2gc03406a.
- [21] Z. Zuo et al., "Small-sized Ag nanoparticle stacked films promoted by sustainedly released surfactants for plasmonic broadband super absorption," *Journal of Alloys and Compounds*, vol. 935, p. 168148, Feb. 2023, doi: 10.1016/j.jallcom.2022.168148.
- [22] R. Ghamarpoor, M. Jamshidi, and M. Mohammadpour, "Achieving outstanding mechanical/bonding performances by epoxy nanocomposite as concrete-steel rebar adhesive using silane modification of nano SiO2," *Scientific Reports*, vol. 13, no. 1, Jun. 2023, doi: 10.1038/s41598-023-36462-0.
- [23] M. Nikkhah Varkani, O. Moini Jazani, M. Sohrabian, A. Torabpour Esfahani, and M. Fallahi, "Design, Preparation and Characterization of a High-Performance Epoxy Adhesive with Poly (Butylacrylate-blockstyrene) Block Copolymer and Zirconia Nano Particles in Aluminum-Aluminum Bonded Joints," *Journal of Inorganic and Organometallic Polymers and Materials*, vol. 33, no. 11, pp. 3595–3616, Jul. 2023, doi: 10.1007/s10904-023-02790-x.
- [24] S. A. Meguid and Y. Sun, "On the tensile and shear strength of nanoreinforced composite interfaces," *Materials & Design*, vol. 25, no. 4, pp. 289–296, Jun. 2004, doi: 10.1016/j.matdes.2003.10.018.
- [25] S. Karimi, A. O. Altayeh, and M. Kargar Samani, "Nanoparticle integration in adhesive and hybrid single lap joints: effect on strength and fatigue life under environmental aging," *Journal of Adhesion Science and Technology*, pp. 1–29, Oct. 2024, doi:10.1080/01694243.2024.2411305.
- [26] M. Li et al., "Improvements of adhesion strength of water-based epoxy resin on carbon fiber reinforced polymer (CFRP) composites via building surface roughness using modified silica particles," *Composites Part A: Applied Science and Manufacturing*, vol. 169, p. 107511, Jun. 2023, doi: 10.1016/j.compositesa.2023.107511.
- [27] M. Grabi, A. Chellil, S. Lecheb, H. Grabi, and A. Nour, "Impact Behavior Analysis of Luffa/Epoxy Composites Under Low-Velocity Loading," *Applied Composite Materials*, Feb. 2024, doi:10.1007/s10443-024-10209-0.
- [28] X. Zou, W. Gao, and W. Xi, "Influence of various damage mechanisms on the low-velocity impact response of composite laminates," *Polymer*

Composites, vol. 45, no. 1, pp. 722–737, Oct. 2023, doi:10.1002/pc.27810.

- [29] A. Karimi, D. Rahmatabadi, and M. Baghani, "Various FDM Mechanisms Used in the Fabrication of Continuous-Fiber Reinforced Composites: A Review," *Polymers*, vol. 16, no. 6, p. 831, Mar. 2024, doi: 10.3390/polym16060831.
- [30] Z. An, X. Cheng, D. Zhao, Y. Ma, X. Guo, and Y. Cheng, "Tensile and Compressive Properties of Woven Fabric Carbon Fiber-Reinforced Polymer Laminates Containing Three-Dimensional Microvascular Channels," *Polymers*, vol. 16, no. 5, p. 665, Feb. 2024, doi:10.3390/polym16050665.
- [31] R. Amara, B. Riadh, A. A. Hassen, N. Mokhtar, and L. Hadji, "Hygrothermal effect of bio-inspired helicoid laminate plate for strengthening damaged RC beam," *Mechanics of Advanced Materials* and Structures, pp. 1–18, Aug. 2024, doi:10.1080/15376494.2024.2392623.
- [32] C. J. Jenkins, M. J. Donough, and G. B. Prusty, "Design and manufacture of mould-free fibre-reinforced laminates with compound curvature," *The International Journal of Advanced Manufacturing Technology*, vol. 131, no. 3–4, pp. 1795–1806, Feb. 2024, doi:10.1007/s00170-024-13226-2.