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IDENTIFICATION OF REGULARITIES IN THE BEHAVIOR OF A GLASS FIBER-REINFORCED POLYESTER COMPOSITE OF THE IMPACT TEST BASED ON ASTM D256 STANDARD

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In this research, commotional analysis based on the finite element analysis (FEA) has been performed to investigate IZOD impact test based on the ASTM D256 standard. The ANSYS model primarily employs a composite constructed of glass fiber-reinforced polyester for the boundary conditions. The CEAST 9050 instrument was used to implement the impacting technique in the experimental inquiry. By employing mathematics, we have calculated that the applied force is 9.2 N. A hammer traveling at a speed of 3.5 meters per second is used to strike the samples, and the results are recorded after each blow. The object of this study is the mechanical properties and structural integrity of the composite material composed of glass fibers and polyester when subjected to impact forces. The main hypothesis of the study encompasses the optimism that the glass fiber-reinforced polyester composite, when put through the Izod impact test in accordance with ASTM D256. Convergence between the overall deformation indicator and the numerical result has occurred. Results from the numerical analysis were examined and confirmed, and compared to those from the experiment. The specimens in this study were totally distorted at three different thicknesses (6 mm, 8 mm, and 10 mm). Deformation was found to be greatest for the thinnest value of thickness considered in the study (6 millimeters), as determined by the results of the computer analysis. This was the case even though the thickness value was not the sole criterion. This is the actual state of affairs. The specimen was subjected to a von-Mises stress at three different thicknesses of 6 mm, 8 mm, and 10 mm. The computer investigation revealed that the Von-Mises stress was highest at the thinnest possible thickness of just 6 millimeters. Internal energy, kinetic energy, and touch energy are only few of the various types of energy that have been studied in the context of energy conservation

Keywords: impact test, shear stresses, total deformation, static structure, IZOD test

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1. Introduction

Nowadays, it is commonly observed that most manufacturers are fussing to produce failure- resistance materials to meet the needs of their customers. However, the main challenge remains to find strong and lightweight materials with minimal cost for different structural parts. This is because most manufacturing industries use conventional materials as raw materials to produce various components. Using conventional materials to manufacture structural parts have many disadvantages, such as higher weight, lower wear, fatigue, and impact resistance. Due to such undesirable material properties, parts fail catastrophically while working. Therefore, to overcome such kinds of problems, evaluating the effectiveness of alternative materials, such as composite materials, that allow overcoming the drawbacks of conventional materials is vital for engineers and manufacturers. High impact resistance and strong materials provide better guarantee during many work activities of the system by maintaining each part of structural strength [1]. Therefore, composites are preferred for impact loading and structural applications [2]. These materials are developed by combining two or more materials in an appropriate weight ratio and orientation angle [3]. Composite materials consist of reinforcement and matrix. The reinforcement may be synthetics or natural fibers [4]. These constituents have different properties with each other and within the composite. In particular, natural fibers are very important in terms of their abundance, renewability, environmental richness, biodegradability, and better economy [5]. Natural and synthetic fiber composites are used to enhance the overall properties of the material and innovate new-generation materials [6]. Moreover, hybrid composites can improve strength properties for structural applications [7]. Its durability and its good mechanical properties, when compared to conventional materials, are its primary manifestations [8]. Composite structures have been used for a variety of structural applications in various industries, such as automotive, aerospace, sporting goods, and home appliances [9]. In many industrial applications, polymeric-embedded composites are widely preferred as an alternative substitute for conventional materials [10]. Fiber composites are particularly important for lighter and highly stiffened applications [10]. Currently, automotive experts need to produce zero-emission and lightweight vehicles. One of the essential reinforcements for such applications was E-glass fiber. It is less expensive and easily available and critical for enhancing the properties of the matrix [11]. The addition of glass fibers to various matrices leads to lower density and improved mechanical properties of the composite. But the oversensitivity of E-glass/polyester composite to impact damage even at lower impact energy and speed during the manufacturing process, and maintenance activities were the major disadvantages. Moreover, matrix cracking and delamination of the composite layers are caused by low-velocity impact [12]. It is used mainly to enhance polymer. For structural applications, E-glass fiber is preferred in various industries. For the numerical analysis, the maximum stress failure criterion was applied. It is extensively used and is simple. As such, each stress on the material must be less than the respective strength of the given material.

Therefore, studies that are devoted to exam how an impact test affects a glass fiber-reinforced polyester composite are scientific relevance.

2. Literature review and problem statement

Polymer composites reinforced with natural fibres have found use in the manufacturing sector as intermediate structural components. Automotive interior panels, outside door panels, the dashboard, and the back seats are all examples of semi-structural uses [12]. A good matrix-to-fiber ratio lessens brittleness and boosts resistance to several types of damage. The correct ratio of matrix to filler material during composite production might accomplish this. In order to better understand how a composite structure with 30 % and 40 % fiber volume reacts to impact. To investigate the failure properties of the composite under low-velocity impact loading, several researchers [13] have conducted experimental, analytical, and numerical simulations. The specimen's surface was cracked, and there were long fractures that were spreading. This is a result of poor compatibility between the matrix and fibers in the composite.

The impact behavior of a hemp and fiberglass composite was also investigated in [14]. The results show that the damage tolerance was broken when 11 % of the hemp fiber was substituted with glass fiber. This indicates that a composite made of both natural and synthetic fibers has superior strength qualities to a composite made entirely of natural fibers. Ansys/LS-Dyna computational software was used in a study of composite constructions [15]. Among the various variables taken into account for determining the abundance of were the impact velocity, shell curvature, and boundary conditions. Their research revealed that as material stiffness is increased, there is an increase in contact force and a decrease in deflections. When applying impact loading conditions to a structural investigation, [16] investigated the impact characteristics of numerous composite materials. The findings show that unidirectional E-glass/Epoxy has the lowest strain energy among ten different composite materials.

Authors of [17] investigated experimentally and numerically the drive shaft for automotive applications considering five different chopped-strand glass fibers and they showed that half a percent of the composite shaft can withstand static loads. Moreover, [18] investigated the damage from impact loading for motorcycle helmets with glass, Kevlar, and carbon fiber composites. The result shows that Kevlar fiber has good impact-resistant regardless of cost. In addition, [19] used varying weight percentages of reinforcement to assess the mechanical characteristics of composite materials. Their findings indicate that the strength qualities increase with increasing fiber concentration. However, the greater likelihood of delamination is a drawback of the composite's increased fiber content. [20] conducted impact analysis on two composite materials, Kevlar 149 and graphite, to evaluate the deformation and stress with an explicit dynamic solver for the striking of 8 mm thick armor with a bullet velocity of 928 m/s. The result shows that graphite has higher impact resistance compared to Kevlar 149. An experimental and numerical analysis was carried out by other researchers [21] to ascertain the damage behavior of glass fiber-reinforced composites when they were hit at low velocity. The conclusion of their study guarantees that the thickness of the composite laminate controls the deflection of the structure since the difference between the numerical and experimental results is very tiny and appears as the expected state.

Also, [22] determined the damping characteristics of the composite shafts by analyzing the different frequency levels. As observed from the result, the stiffer shafts could be produced by adding layers in a transverse direction where the composites are boron/epoxy and the smallest frequencies are observed. Similar to [23], investigated the impact of three low-velocity strikes on a cant lever beam that was adherently bonded. Because the maximum strain energy was focused in the bonded region of the material, higher strain energies and corresponding stresses occurred in the final step. Therefore, this stress concentration location and impact site may lead to catastrophic failure and reduced load-bearing capabilities [24].

However, [25] explores the damaged region of an E-glass/epoxy composite used in ballistic impact. Delamination ability of the composite construction was shown to be a determining factor in ballistic performance. Researchers of [26] experimented with hybrid epoxy/Nano-clay/glass fiber using Izod and Charpy impact testing machines, and the impact strength capabilities were determined. Finally, as observed from the result, the weight percentage of nano-clay is the main determinant of the composite materials and when it is increased to ten percent, the impact strength decreased and the material is easily delaminated. Authors [27–29] used the instrumented Charpy impact test to measure the hybrid glass fiber reinforced epoxy's capacity to absorb impact energy and compared the hybrid composite's energy absorption strength to that of pure glass fiber/epoxy. We can therefore create a securely adherent and delamination-free composite structure by understanding the correct and balanced quantities of fiber and matrix in the composite. This permits the production of numerous structural components utilizing

E-glass/polyester composite materials for the automotive sector.

Therefore, this study employs finite element analysis in line with ASTM D256 standard to investigate the impact test's impact on a glass fiber reinforced polyester composite.

3. The aim and objectives of the study

The aim of the study is identifying influence of the impact test on a glass fiber-reinforced polyester composite of an IZOD sample based on ASTM d256 standard. The computational analyses have been conducted using FEM.

To achieve this aim, the following objectives are accomplished:

– to investigate the deformation due to thickness;

– to investigate the Von-mises stress due to thickness;

– to study the Energy conservation;

– to investigate the momentum due to the thicknesses.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

The object of this study is the mechanical properties and structural integrity of the composite material composed of glass fibers and polyester when subjected to impact forces.

The main hypothesis of the study encompasses the optimism that the glass fiber-reinforced polyester composite, when put through the Izod impact test in accordance with ASTM D256, will perform better under impact because of the reinforcement, and that a finite element analysis will reveal information about stress distribution and failure mechanisms, possibly confirming the ASTM standard's applicability and illuminating the role of microstructural factors in impact behavior.

Simplifications adopted in the work include treating the material as homogeneous and isotropic despite its composite nature, ignoring potential manufacturing flaws or variations in the material properties, assuming ideal boundary conditions that might not accurately reflect real-world scenarios, and using simplified geometry for modeling rather than a complex real-world geometry. Additionally, for the sake of simplicity, certain environmental aspects like the impacts of temperature and humidity may be overlooked.

4. 2. Primary Boundary conditions

The ASTM D256 standard impact testing equipment was used to carry out the test, and the parameters for the test required a pendulum failing height of 0.0204 meters, a failing angle of 120 degrees, and a striking (impact) velocity of 3.5 meters per second. The length, width, and thickness of the impact specimens are each 65 mm, 12.5 millimeters, and 3 millimeters, respectively, and they each have a "V"-a notch that is 2 millimeters deep and is angled at 45 degrees. An Izod impact testing equipment was used to perform the test on a total of nine different impact specimens, each of which had three different fiber-to-matrix weight ratios assigned to it when the test specimens were constructed.

4. 3. Geometry and meshing

The impactor and the plate make up the bulk of the meshing. The ANSYS model has been used to mesh both of them (explicit dynamic tool). ANSYS Mesh generation was performed with the aid of meshing, which was used to generate meshes for the situation at hand. By eliminating some of the original, potentially infinite number of particles in a model, meshing makes the model easier to work with. Fine mesh was developed utilizing a predefined grid structure to facilitate the acquisition of accurate data. Because of this, the mesh may be manufactured. Using curvature size with a coarse mesh and element size with face meshing helped accomplish the desired output of a fine mesh. All of the wedge's zones' worth of binary nodes have been generated, and the grand total is 43532. A diagram of this mesh type in two dimensions is shown in Fig. 1. The only part of the model that has been built and modelled so far is the symmetric part because of the symmetry of the 3D wedge.

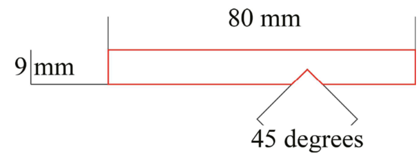

Fig. 1. Geometry of IZOD sample

To determine the numerical result, Ansys explicit dynamics software was used, which is the other element of Ansys packages and is preferred for analysis purposes. To make our analysis more robust and support the software to easily solve for different equations during the analysis, triangular elements of meshes are used as shown in Fig. 2, grid independence test was performed by varying mesh size before analysis. At 0.05 mm mesh size 1420601 number of triangular elements has been obtained, which is capable to produce better results in a short time. After this mesh, the number of elements is almost similar and does not affect the result, but requires a longer execution time. Therefore, for this analysis, all the corresponding values can be used for the mentioned mesh size and the number of elements. The benefit of using these values are minimizing computer processing time during analysis and getting better simulation results in a shorter period.

As can be seen in Fig. 2, we make use of triangular elements of meshes so that our analysis will be more reliable and so that our software will have an easier time solving for various equations as it performs the analysis. Before doing the analysis, a grid independence test was carried out by adjusting the mesh size.

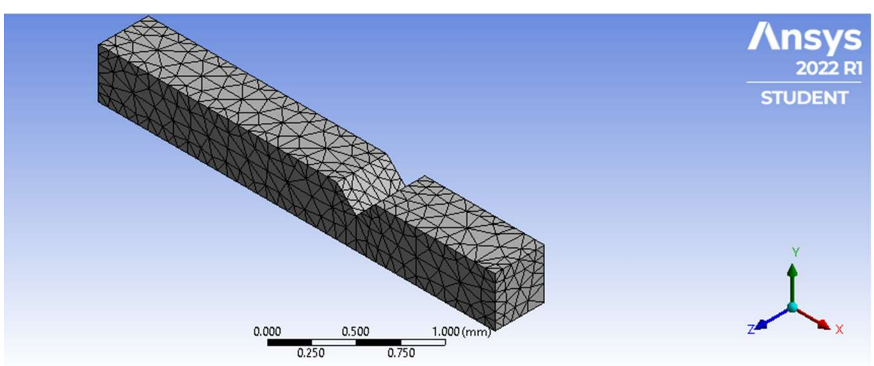

Fig. 2. The meshed model

4. 4. Material properties

The mechanical and physical properties of the model need to be analyzed and specified before the computational domain can be applied. In this analysis, the various definitions of an E-Glass with a Plain weave were taken into consideration: Many different values for the mass and the modulus of elasticity. Throughout the simulation process, the density is another parameter that needs to be defined. Table 1, which may be seen right over here, is a listing of the mechanical characteristics of the various materials that are currently available.

Table 1

Mechanical engineering of polyethylene terephthalate glycol (PETG)

Material	Maximum tensile stress (MPa)	Passion ratio	Density (g/cm^3)
Composite materials	22.9	0.31	1.932

Before the computational domain can be used, the mechanical and physical aspects of the model need to be studied and stated. This must be done before the model can be used. During the course of this investigation, the following explanations of what constitutes an E-Glass with a Plain weave.

A convergence test is the method that has been chosen to be used in the empirical studies that have been conducted on the connection. This method is used to carry out the results of the numerical analysis. The purpose of this test is to evaluate and contrast two different sets of findings that have been computed numerically. It has been decided that the life forecast that is offered in the fatigue tool would be the primary indicator for convergency. This was reached through consensus. The method for arriving at convergence has been finished after taking into account the two separate solutions displayed in Fig. 3. The number of cycles counted at the beginning for the first solution was 665, whereas the number of cycles counted at the beginning for the second solution was 445.7. The mesh that is utilized in the current model has been updated so that it depicts the second solution in a more accurate manner.

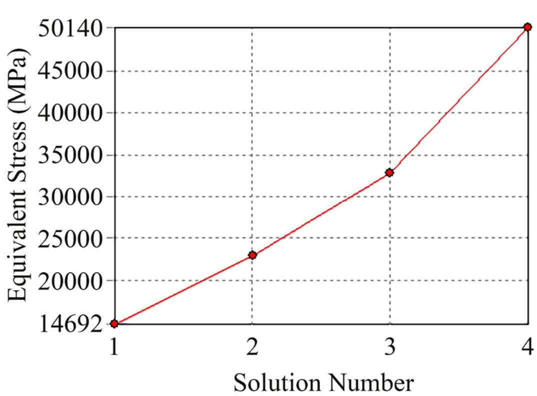

Fig. 3. Convergence test based on the total deformation

The test's objective is to compare and contrast two distinct sets of findings that have been computed numerically in order to better understand the relationship between them. It has been agreed that the life forecast that is provided in the fatigue tool will serve as the key indicator for convergency.

5. Results of the impact test on a glass fiber-reinforced polyester composite of an IZOD sample based on ASTM D256 standard

5. 1. Deformation due to thickness

Fig. 4 shows that the specimen was subjected to total deformation at three distinct thicknesses: 6 mm, 8 mm, and 10 mm. According to the findings from the numerical analysis, the highest amount of deformation occurs at the thickness that is the least, which is 6 mm. The specimen went through the processes of being statically loaded with 50, 100, 150, and 200 N, respectively, before being released. The specimen's thickness of 6 mm resulted in a deformation of 1.9 mm when subjected to a force of 200 Ns. When the specimen was exposed to an impact force of 200 Ns, the maximum deformation was 1.4 mm, while for the same submitted load it reached 1.39 mm. The specimen had a thickness of 10 mm. However, when an impact load of 50 N is applied to the same specimen, the smallest amount of deformation, which is 0.5 mm, is produced.

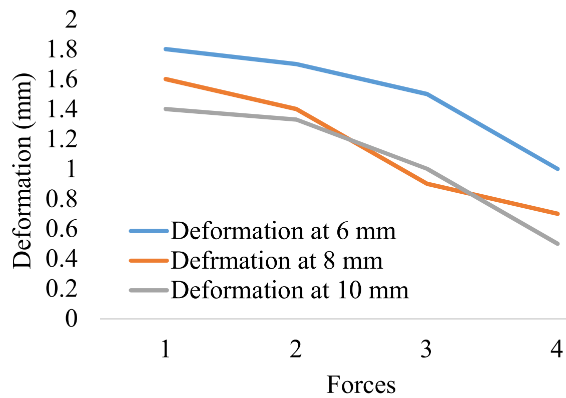

Fig. 4. Total deformation with different thickness

The effect that the impact had on the izod sample is graphically illustrated in Fig. 5, which may be seen here. The numerical findings showed that the maximum distortion is obtained at a thickness of 3 mm, whereas it is 6 mm for the one that is the thinnest. According to the findings, the point at the very end of the sample had the greatest amount of deformation.

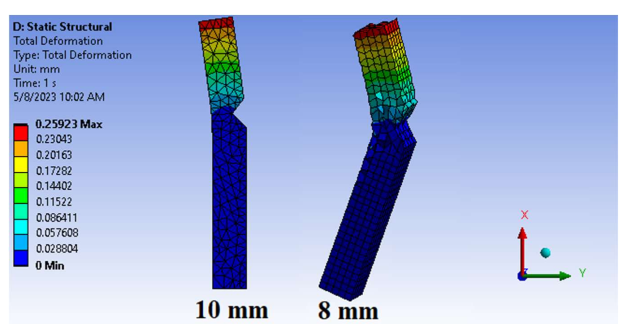

Fig. 5. Shows the graphical illustration of the effect total deformation

The conclusion drawn from the research is that the point that represents the very end of each sample demonstrates the greatest degree of deformation overall. As a distorted portion, it has reached 0.25 mm in thickness.

5. 2. Von-Mises stress due to thickness

As can be seen in Fig. 6, Von-Mises stress was applied to the specimen at three different thicknesses (6, 8, and 10 mm). According to the numerical results, the greatest amount of Von-mises stress takes place at the smallest thickness (6 mm). The specimen went through the motions of being loaded statically with 50, 100, 150, and 200 N respectively. When the specimen had a thickness of 6 mm, the Von-mises stress reached 21443 MPa when the force was 200 N. For the specimen that had a thickness of 10 mm, the maximum Von-mises stress reached 19872 MPa when it was subjected to an impact force of 200 Ns, while at the same subjected load it reached 19872 MPa. Whereas for the same specimen, the minimal Von-mises stress of 17934 MPa is achieved when an impact load of 50 N is applied

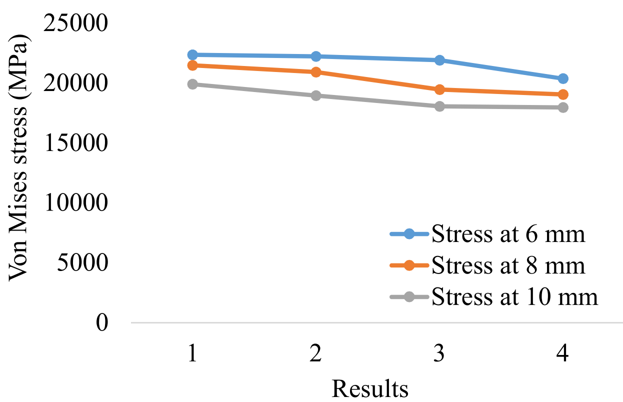

Fig. 6. Von-Mises stress due to thickness: 1 — 50 N; 2 — 100 N; 3 — 150 N; 4 — 200 N

The portion of the specimen that was affected by the impacting load is illustrated in Fig. 7 in terms of the Von-Mises stress. According to the findings from the numerical analysis, the stress level has now achieved its maximum value of 22332 MPa. At the notch, because it had the smallest cross-section area, the Von-Mises stress was at its highest possible value. The acute angle of the structure is subjected to an increasingly greater concentration of stress.

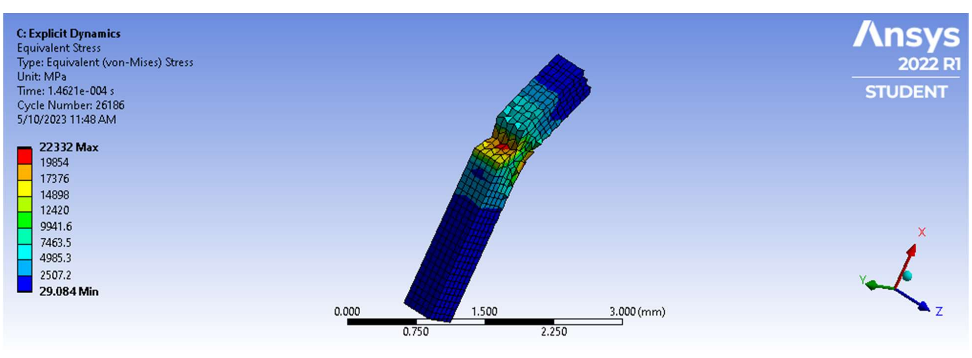

Fig. 7. The graphical illustration of the effect stress distribution

The results of the numerical analysis suggest that the level of stress has now reached its maximum value of 22332 MPa. This is in accordance with the conclusions of the study. The Von-Mises stress was at its maximum conceivable value at the notch because it had the smallest cross-section area of any other part of the structure.

5. 3. Energy conservation

Fig. 8 shows when the impact load hits the specimen, the kinetic energy, and internal energies remain lower. Since the speed of the striker has been decreased due to the impact on the specimen, this triggers the occurrence of lower energy associated with the motion of the striker. However, after impact, the load rebounds at a certain speed, and the kinetic and internal energies are increased. In addition to this, hourglass energy appears in the distorted part of the specimen. It indicates the deformation elements and as the cycle increased, it also increased proportionally. On the other hand, contact energy has occurred between the surface of the striker and its target. This interface energy was generated when the contact force was multiplied by the displacement of the target nodes and it depends on the intensity of the impact force and the change of deformation. As can be seen from the figures below, the contact energy is lower and steadily increases with increasing time (cycles). This affirms the composite's uniform resistance to impact penetration through fiber and matrix. As shown in Fig. 8, kinetic and internal energy are smaller when the impact load hits the sample. Thus, during the impact, the striker stays attached for a short time and its motion was lowered until the load bounce and increases gradually. According to the findings of this research, there are four distinct forms of energy that can explain the response of the composite material to the impact procedure. At the beginning of the experiment (0 second), the kinetic energy has the optimal value to reach 9.7e-5, and it is gradually decreasing as more time is applied. The duration of the impact test as a whole is equal to 6e-5 seconds. The energy of the hourglass has undergone a significant shift. The initial value was 3.5e-7 J at 0 sec, and it gradually decreased to 1e-5 sec before reaching a stable state. While the explanation for internal energy is somewhat different, the basic idea is the same: it starts at zero time and needs 3.5e-7 J to leap to its maximum value. After that, it continued to fall until it reached a stable state at the conclusion of the test.

Fig. 9 illustrates the many forms of energy that are monitored within the framework of the modelling and simulation process. The sum total of the energy required to simulate the operation of the four primary energy sources. The energy that serves as a point of reference is at the very pinnacle of the list of energies that are respected throughout all of time. The simulation procedure demonstrated that the error energy is zero all the way up until the very end of the simulation process, which lasted from 0 seconds to 6 e-5. As a result of the fact that this energy is necessary for work during the time that was spent, the simulation demonstrated that work is consistent up until the end of the simulation process.

In terms of the strain energy, the portion of the specimen that was impacted by the load is illustrated in Fig. 10. The computational findings have shown that the maximum value of the strain energy, which is 0.118 mJ, has been attained. The notch experienced the greatest amount of strain energy since it had the smallest cross-sectional area. Additional strain is being energy on the structure's acute angle at this point.

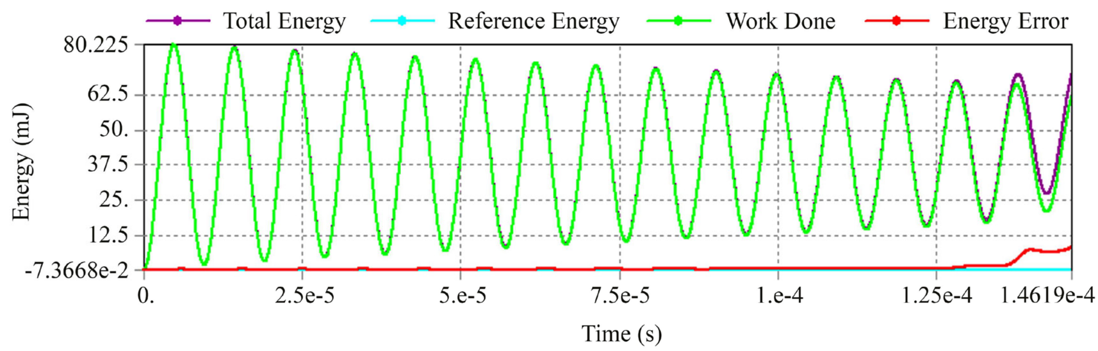

Fig. 8. Energy conservation

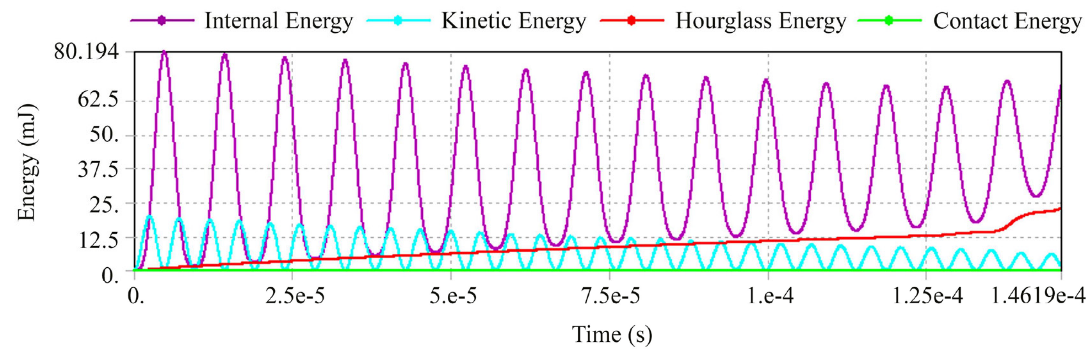

Fig. 9. Energy summery

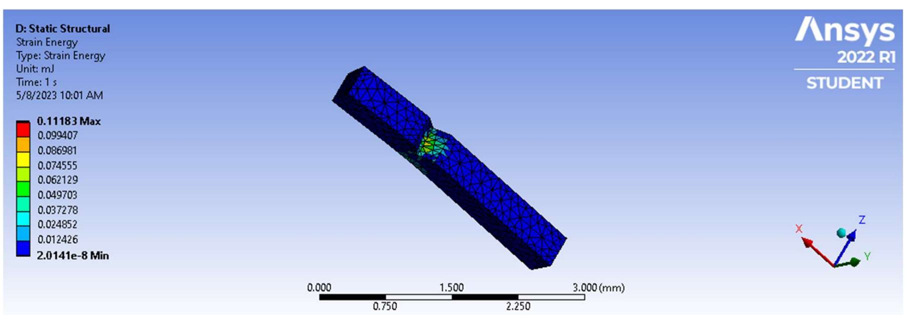

Fig. 10. Shows the graphical illustration of the effect energy distribution

Because it possessed the smallest cross-sectional area, the notch was subjected to the largest amount of strain energy during the process. At this moment, the acute angle of the structure is being subjected to additional strain and energy.

5. 4. Momentum investigation

The upper limit of momentum is being transferred in the direction that is perpendicular to the Z axis. This is because the direction that the impact is being made is perpendicular to the Z axis. On top of that, the impulse will also be directed in the Z direction at the same time. At 0 seconds, the minimum direction (2e-5 N.s.) caused the minimum momentum to begin moving. This motion was caused by the start of the timer. It must reach its maximum value of 3e-5 N.s in 0.5e-5 seconds in order for it to maintain its stability until the end of the test as shown in Fig. 11.

The time increment that occurred during the simulation process for both the impactor and the plate is depicted in Fig. 12. Where is harmless with 1.06e-9 seconds relative to 0 seconds and dropped to 1e-9 till the end of the simulation

Fig. 12 provides a visual representation of the time increment that was experienced by both the impactor and the plate while the simulation was being run.

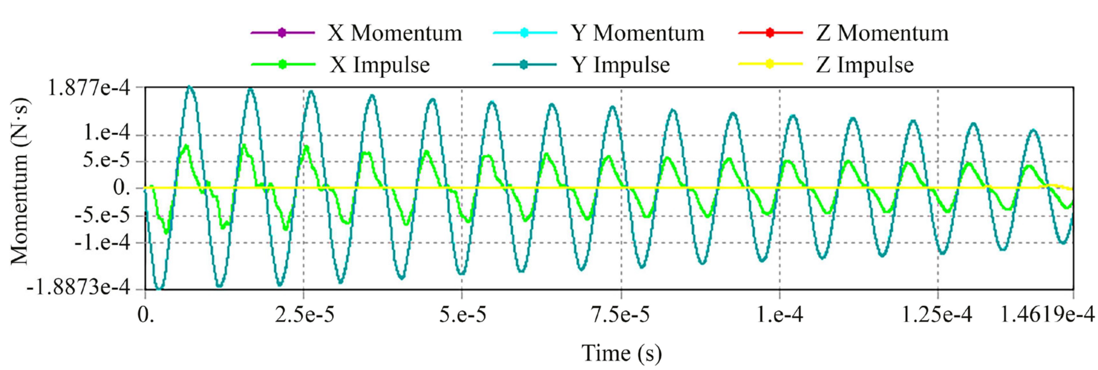

Fig. 11. Momentum summery

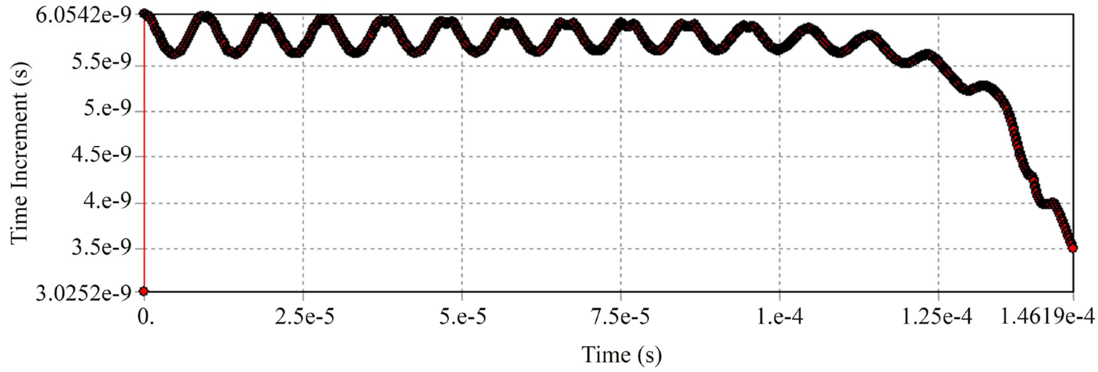

Fig. 12. Time increment

6. Discussion of the impact test on a glass fiber-reinforced polyester composite of an izod sample based on ASTM D256 standard

The investigation provides observations on the performance and behavior of the researched structure. The greatest amount of deformation that can occur is seen in Fig. 4 and has a value of 1.8 units when the material thickness is 6 millimeters. It is necessary for engineers and designers to have an understanding of the maximum amount of deformation that a particular material can sustain before it begins to impair either its structural integrity or its performance. The Von-Mises stress distribution is depicted in Fig. 6 as a function of the thickness of the material, with the highest value being 22322 MPa. The Von-Mises stress may be used to find possible failure zones by integrating the stresses from a number of different sources. This information is essential for making educated judgments on safety margins, material choices, and any reinforcements or design changes that may be necessary to boost the structural robustness of the building.

The diagrams in Fig. 8 and 9 analyze the contact, kinetic, and hourglass energies, and they break down the ideas of energy conservation in detail. When it comes to producing results that are accurate and consistent, numerical simulations and finite element analysis primarily rely on the principle of energy conservation. The legitimacy of the simulation approaches and the precision of the results are both confirmed by these data, making them helpful for engineers. In conclusion, the investigation of momentum in three dimensions (x, y, and z) relative to the thickness of the material is depicted in Fig. 11. If the structure's momentum distribution is understood, then the dynamic behavior of the structure under a variety of different loading scenarios may be anticipated with more precision. This information is absolutely necessary for structural designers who are looking to attenuate vibrations, regulate dynamic reactions, and improve overall performance. Fig. 12 provides a visual representation of the time increment that was experienced by both the impactor and the plate while the simulation was being run.

The presented study has limits in terms of the particular range of loads, and the applicability of the results is restricted to being applicable solely within the context of the ASTM D256 standard for impact testing. Because the study focuses on one particular kind of material – e-Glass with a Plain weave – it is possible that the findings cannot be generalized to apply to other kinds of composites. The results generated from the finite element analysis, including total deformation, Von-Mises stresses, and energy consumption, are applicable within the defined scope of loads and impact circumstances prescribed by ASTM D256. This standard was developed by the American Society for Testing and Materials (ASTM).

The study's disadvantages may include a concentration on e-Glass with a Plain weave, a limited range of weights, and limited applicability to ASTM D256 standard impact testing. Expanding the range of loads investigated in future studies will better reflect the variety of impact situations that may arise. The study's applicability would be enhanced by using multiple impact testing standards or actual loading situations. Different behaviors can be attributed to the wide variety of composite materials and weave patterns available. Improving the reliability of the finite element analysis through corroboration with experimental data. If assumptions can be reduced and material attributes can be specified in more detail, precision can be increased. Results can be evaluated for their dependability by doing sensitivity analysis on material attributes. Providing thorough analytic setup details to ensure reproducibility and transparency will make it easier for other researchers to independently verify your findings. By resolving these caveats, the study's findings on the impact behavior of composites will be more robust and its practical relevance will grow.

The study's development may involve advanced material characterization, multiscale analysis, and rigorous experimental validation to enhance accuracy. Addressing impact modeling variability and dynamic effects could provide a comprehensive understanding of composite behavior. However, challenges arise in obtaining specialized materials, managing computational resources, and achieving mesh convergence. Dealing with nonlinear behavior and interlaminar effects adds complexity. The study may also require sophisticated probabilistic analysis to account for impact event variability. Overcoming these difficulties demands expertise, time, and resources, but it will result in more reliable insights into composite impact behavior and broaden the study's applicability in real-world scenarios.

7. Conclusion

1. The research conducted on the deformation caused by thickness demonstrates that the maximum value of 1.8 units is reached when the thickness of the material reaches 6 millimeters. This discovery is essential for optimizing material

thickness in a variety of applications so as to properly regulate and manage deformations, hence maintaining structural stability and performance.

2. The results of an investigation of the Von-Mises stress in relation to the thickness of the material, which reveals a maximum value of 22322 MPa. When determining possible failure spots and safety margins, it is essential to have a thorough understanding of stress distribution as well as stress concentration regions. Because of this data, engineers are able to make educated design decisions and put necessary safeguards into place to reduce stress-related difficulties.

3. The study of energy conservation-centers on the energies of contact, kinetics, and the hourglass. It is absolutely necessary to validate energy conservation in numerical simulations in order to guarantee the correctness and dependability of the findings. This information helps in the process of making informed judgments based on the results of the simulation and allows one to have faith in the simulation methods that were utilized.

4. It is absolutely necessary to have a solid grasp of momentum transfer in order to accurately forecast the dynamic behavior of the structure under a variety of loading circumstances. These statistics are extremely helpful for managing dynamic responses in practical applications, as well as improving designs, lowering vibrations, and minimizing vibrations.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research.

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Data availability

Data will be made available on reasonable request.

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