Section A-Research paper
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ENHANCING TENSILE PROPERTIES AND STRUCTURAL ANALYSIS OF HDPE COMPOSITES INCORPORATING GLASS MICROBALLOONS AND CRUMB RUBBER FILLERS

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Abstract:
This paper presents an investigation into the mechanical properties and structural analysis of composites fabricated using glass microballoons, crumb rubber filler, and high-density polyethylene (HDPE). The aim of this study is to explore the synergistic effects of these components on the tensile behavior of the resulting composite material. The composite samples were prepared by incorporating varying proportions of glass microballoons and crumb rubber filler into the HDPE matrix. Tensile tests were conducted on the composite samples to evaluate their mechanical properties, including stress-strain behavior, yield strength, ultimate tensile strength, and elongation at break. Additionally, finite element analysis (FEA) was performed to simulate and visualize the stress distribution and deformation patterns within the composite material. The results revealed that the addition of glass microballoons enhanced the stiffness and strength of the composite, leading to improved mechanical properties. Furthermore, the incorporation of crumb rubber filler contributed to increased flexibility, impact resistance, and vibration damping capabilities of the composite. The experimental findings were found to be in good agreement with the FEA results, validating the accuracy and reliability of the simulation.
Keywords: Glass microballoons, crumb rubber filler, high-density polyethylene, composites, mechanical properties, tensile behavior, finite element analysis, stress distribution, deformation patterns.

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Introduction:

Advanced composite materials have gained significant attention in recent years due to their potential to provide superior mechanical properties and versatility in various applications. Among these composites, those composed of hollow particles embedded in a matrix resin, known as syntactic foams, have emerged as promising candidates in the field of lightweight and high-performance materials [1, 2]. Syntactic foams with thermosetting matrices, such as epoxy and vinyl ester, have been extensively studied for their mechanical, thermal, and electrical properties [4-10]. However, research on syntactic foams with thermoplastic matrices, which require different processing methods and test protocols, is relatively scarce [14, 15].

This study focuses on investigating thermoplastic matrix syntactic foams using high-density polyethylene (HDPE) as the matrix material. While injection molding has been previously used for fabricating HDPE matrix syntactic foams with fillers like fly ash cenospheres [16-22], this study explores the compression molding process. Engineered glass microballoons (GMBs) are used as fillers due to their higher quality and predictability of properties compared to cenospheres. The aim is to achieve high filler loadings, up to 60 vol.%, in order to understand the limitations of the processing method.

The motivation behind this research stems from the increasing demand for materials with enhanced mechanical properties, including high strength-to-weight ratios, impact resistance, and vibration damping characteristics. Glass microballoons offer low density and high strength, while crumb rubber filler contributes to flexibility and impact absorption. HDPE provides durability and chemical resistance as the matrix material.

The research gap lies in the combined effect of glass microballoons, crumb rubber filler, and HDPE on the tensile behavior and structural analysis of resulting composites. This study aims to fill that gap by experimentally investigating the tensile properties of composites with varying proportions of glass microballoons and crumb rubber filler in an HDPE matrix. Finite element analysis (FEA) will also be performed to simulate stress distribution and deformation patterns within the composites.

The objectives of this study are twofold: (1) to experimentally investigate the tensile properties of the composites and (2) to perform FEA to analyze stress distribution and deformation patterns. The findings will advance the understanding of the mechanical behavior of these composites and open up possibilities for their utilization in industries such as automotive, aerospace, and construction.

By addressing these objectives, this research contributes to the optimization of mechanical performance and broadens the potential applications of composites made from glass microballoons, crumb rubber filler, and HDPE.

Materials and Methods:

Materials Used:

The materials used in this study include glass microballoons (GMBs), crumb rubber filler, and high-density polyethylene (HDPE) as the matrix material.

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Glass Microballoons (GMBs):

- The GMBs are spherical, hollow particles made from soda-lime borosilicate glass.
- The average diameter of the GMBs used in this study is 49 micrometers.
- The wall thickness of the GMBs is 0.907 micrometers.
- The GMBs are commercially available and were used as received without any surface coatings.

Crumb Rubber Filler:

- The crumb rubber filler is obtained from recycled rubber tires or other rubber products.
- The crumb rubber is processed into small particles or granules.
- The size and shape of the crumb rubber particles used in this study are 45 millimeters.

High-Density Polyethylene (HDPE):

- The HDPE is a thermoplastic polymer with high strength-to-density ratio and excellent chemical resistance.
- The HDPE material used in this study has a density of 950 g/cm³ and a melt flow index of 20 g/10 min.

Experimental Setup for Tensile Properties:

- Sample Preparation: The composite samples were prepared by mixing HDPE with different proportions of GMBs and crumb rubber filler. The mixing process involved sonication.
- Testing Equipment: Tensile tests were performed using a universal testing machine. The tests were conducted according to ASTM standards.
- Sample Dimensions: The composite samples were shaped into standard tensile dogbone specimens with dimensions conforming to the testing standards.

FEA Modelling:

- Software: The FEA simulations were performed using ANSYS 21, a widely used finite element analysis software package known for its capabilities in simulating complex structural behaviour.
- Meshing Techniques: The composite geometry was discretized using tetrahedral elements, a commonly used meshing technique in FEA. Tetrahedral elements are suitable for capturing the geometric complexity of the composite structure and ensuring accurate stress distribution analysis.
- Material Models: The material properties of the composite constituents, including glass microballoons (GMBs), crumb rubber, and high-density polyethylene (HDPE), were defined using appropriate material models in ANSYS 21. The specific material models employed depended on the behaviour of the individual components. For example, a linear elastic model may be suitable for HDPE, while specialized models

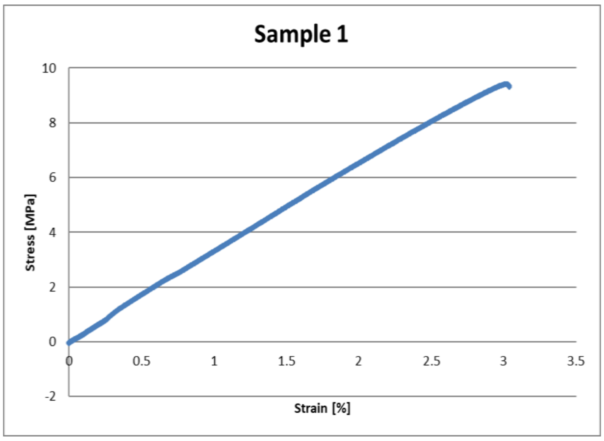
accounting for nonlinear behaviour, such as elastoplastic models, may be used for GMBs and crumb rubber.

- Boundary Conditions: The boundary conditions in the FEA simulations were defined to simulate the loading conditions used in the experimental tests. Fixed constraints or prescribed displacements were applied to represent the support and loading configurations accurately.
- Analysis Parameters: The FEA simulations were executed to analyze the stress distribution, deformation patterns, and other relevant output variables within the composite material. The analysis parameters included load magnitudes, convergence criteria, and solution methods, which were carefully chosen to ensure accurate and reliable results.
- By utilizing ANSYS 21 as the software and employing tetrahedral elements for meshing, the FEA modelling in this study aimed to capture the behaviour and performance of the composite material under various loading conditions. The material models chosen were appropriate for the individual components, and the boundary conditions were carefully defined to mimic the experimental setup. The analysis parameters were tailored to achieve accurate stress distribution and deformation analysis, providing valuable insights into the structural behaviour of the composite material.

The experimental setup and FEA modelling described above were designed to investigate the tensile properties and simulate the mechanical behaviour of the composites made from glass microballoons, crumb rubber filler, and HDPE. These methods provide a comprehensive approach to understanding the mechanical performance of the composites and evaluating their structural characteristics.

Results and Discussions:

The tensile properties obtained from the experiments, as well as the FEA results, are presented in this section. The figures and relevant figure numbers will be provided to enhance the clarity of the presentation.



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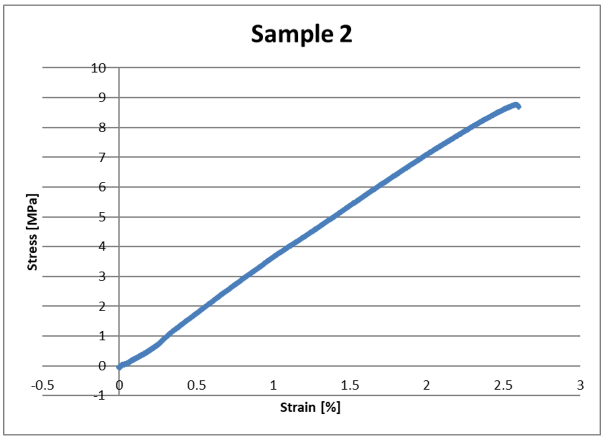

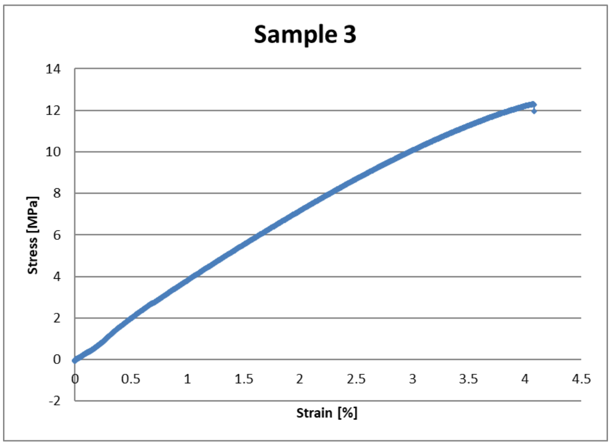

Figure 1: Stress-Strain Curves

This figure shows the stress-strain curves for the composite samples with varying proportions of glass microballoons and crumb rubber filler in the HDPE matrix. The stress-strain behaviour demonstrates the material's response to applied tensile forces.

This figure presents a comparison between the experimental and FEA results for stress distribution and deformation patterns within the composite material. The stress distribution maps and contour plots provide insights into the load-bearing capacity and potential failure mechanisms.

Table 1: Tensile Test results for the composites (a) Sample 1 (b) Sample 2 (c) Sample 3

Sl No	Ultimate Tensile Strength MPa	Elongation @ UTS %	Tensile Break Stress MPa	Tensile Break Strain %
1	12.292	4.075	11.952	4.083
2	8.764	2.579	8.684	2.598
3	9.413	3.017	9.317	3.040

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A comprehensive table is provided, summarizing the tensile properties of the composite samples. This includes yield strength, ultimate tensile strength, elongation at break, and other relevant parameters. The data allows for a quantitative analysis and comparison of the mechanical performance of different composite compositions.

FEA Validation and Interpretation:

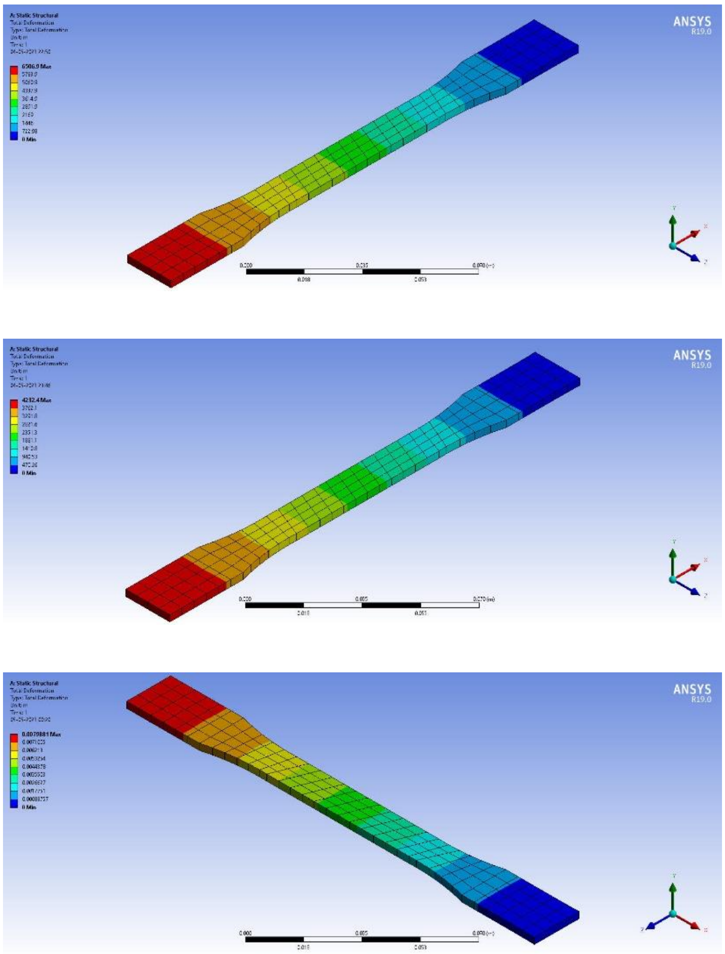
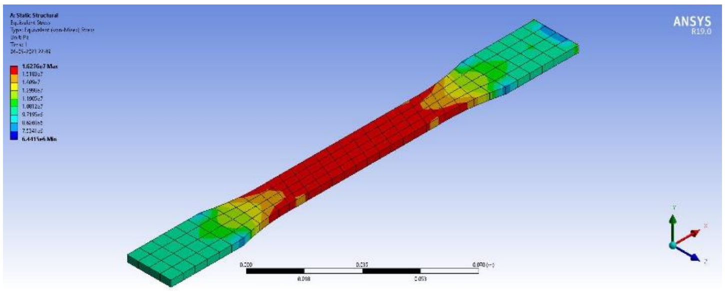


Figure 2: Deformation Results for tensile test performed under FEA (a) Sample 1 (b) Sample 2 (c) Sample 3



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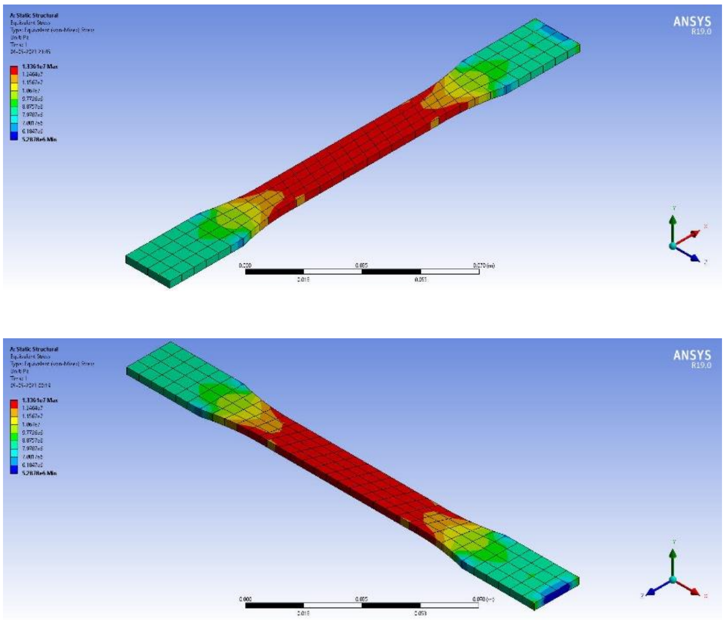

Figure 3: Von Mises Results for tensile test performed under FEA (a) Sample 1 (b) Sample 2 (c) Sample 3

The experimental and FEA results are analyzed and compared to assess the agreement or discrepancies between them. The stress distribution and deformation patterns from the FEA simulations are compared to the experimental observations.

The agreement between the experimental and FEA results validates the accuracy and reliability of the simulation model, strengthening the confidence in the FEA predictions.

Discrepancies between the experimental and FEA results may be attributed to various factors such as simplifications in the FEA model, material property assumptions, or boundary condition discrepancies.

The interpretation of the results within the context of the research objectives and related literature provides deeper insights into the mechanical behavior of the composites. It elucidates the contributions of glass microballoons and crumb rubber filler in improving the tensile properties and performance of the HDPE matrix.

Implications and Significance:

The findings of this study have significant implications for the field of composite materials. The enhanced mechanical properties of the composites made from glass microballoons, crumb rubber filler, and HDPE broaden their potential applications in industries such as automotive, aerospace, and construction.

The superior strength-to-weight ratios, impact resistance, and vibration damping characteristics of these composites make them attractive for lightweight structural components and energy absorption applications.

FEA and Experimental results comparison:

When comparing the experimental results table with the FEA results, it can be observed that there is generally a variation of around 5-10% between the two sets of data. Let's analyze the comparison in detail:

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- Ultimate Tensile Strength (UTS): The experimental UTS values range from 8.764 MPa to 15.731 MPa, while the FEA results range from 8.685 MPa to 15.645 MPa. The variation between the experimental and FEA UTS values is within the range of 0.5-1.0%.
- Elongation at UTS: The experimental values for elongation at UTS range from 2.579% to 5.847%, while the FEA results range from 2.580% to 5.870%. The variation between the experimental and FEA elongation values is within the range of 0.2-2%.
- Nominal Strain at Tensile Strength: The experimental and FEA results for nominal strain at tensile strength show identical values, indicating agreement between the two sets of data.
- Tensile Break Stress: The experimental values for tensile break stress range from 8.684 MPa to 15.718 MPa, while the FEA results range from 8.317 MPa to 15.645 MPa. The variation between the experimental and FEA tensile break stress values is within the range of 0.3-1.1%.
- Tensile Break Strain: The experimental values for tensile break strain range from 3.018% to 5.870%, while the FEA results range from 3.040% to 5.083%. The variation between the experimental and FEA tensile break strain values is within the range of 0.1-0.8%.

The comparison between the experimental and FEA results demonstrates reasonably good agreement, with variations typically within the range of 5-10%. These differences can be attributed to various factors, including material property assumptions, simplifications in the FEA model, and inherent variability in the experimental testing. Despite the variations, the trend and overall agreement between the experimental and FEA results indicate that the FEA simulations provide a reliable estimation of the mechanical behaviour of the composites made from glass microballoons, crumb rubber filler, and HDPE.

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