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Design and Analysis of a Novel Industrial Safety Helmet using Composite Materials

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Abstract

The design of industrial safety helmet is crucial, and adding an extra protective layer made of composite materials can enhance their ability to protect workers from head injuries. The proposed work evaluates the different types of composites for suitability in the manufacturing of safety helmets. Finite Element Analysis (FEA) simulations were performed to evaluate the structural integrity and impact testing conducted to determine their effectiveness under real-world conditions. The results showed that the composite material effectively absorbed and redistributed impact force, reducing injury risk and severity. Comfort and usability were also evaluated, and the helmet's weight remained acceptable, making it practical for extended use. This paper contributes to promoting innovative designs to improve worker safety in high-risk zones of various mechanical industries.

Keywords: Composite material; Industrial safety helmet; Deformation; Static stress simulation; Finite Element analysis

Abbreviations: HIT: Helmet Impact Testing; PC: Polycarbonate; HDPE: High Density Poly Ethelene; ABS: Acrylonitrile Butadiene Styrene

Introduction

The safety of the workplace is a crucial factor in determining the effectiveness and productivity of the worker. Unfortunately, the ignorance of safety factors still prevails in many developing countries, where laborers often face significant losses due to accidents or hazards. The industrial sector of these countries is more prone to hazards and accidents, which makes safety equipment crucial. The study carried out by Long et al. [1] to identify human head model for use in LS-Dyna, developing an accurate FEM model of a typical industrial hard hat and determining the threshold at which a human being would experience injury using two different injury criteria; The first injury criteria is HIC which is widely accepted measure of the likelihood of head injury. The formulation of the HIC score is based on the resultant translational acceleration and time. The study concluded with proposed limits for injury mechanisms. Author Santos [2] addressed the current test standard that evaluates hard hat performance which does not likely assess their ability to mitigate head accelerations from such impacts. To address this gap in knowledge, three investigations were pursued as part of this research. Lee et al. [3] suggested the research for materials selection for construction hard hats. The material selection process is carried out by using a material selection Ashby chart. Jacob et al. [4] studied the results of a research project focused on helmet protection under impact of head to ground, and impact of an object to head. Three models were chosen to best describe the helmet action: bicycle, motorcycle and construction helmet. The study proposed by Shinde et al. [5] aimed to achieve an improvement in shell material by using composite material, the main goal of material selection is to increase the material properties and to minimize cost in the context of product design, while meeting product performance goals. Bottlang et al. [6] compared six industrial safety helmets comprising three categories were evaluated: two full-brim hardhats, two climbing-style safety helmets, and two helmets equipped with dedicated rotation-damping technologies. Helmet testing was conducted at the Helmet Impact Testing (HIT) facility of the Portland Biomechanics Laboratory. Author Baszczyński [7] undertook a research project aimed at the study of, amongst others, the use of industrial safety helmets in conjunction with other types of PPE including eye and face protection devices, respiratory protective equipment and thermal protective clothing. As a result, efforts were undertaken to develop an appropriate research method and a test stand that would enable determination of the phenomena occurring upon falling weight impact on safety helmets used in combination with protective spectacles/goggles. studied the model developed from two layers of helmet. Ahmad and Kumar [8] proposed a model and designed the helmet model in Catia with specified dimensions and analysis is carried out in Ansys workbench 15, the main objective was to list out the best material which suits for the helmet. From the various literature it has been identified that still there is a scope in the design and material selection of industrial helmets. The proposed work aims to analyze suitable material for a proposed design that can protect the wearer from injuries during impacts and collisions. The study involves examining the behavior of various materials under impact loads and observing the distortions they cause on the helmet. A 3D modeling and simulation software is utilized to analyze different types of composite materials and types of impact loads for the proposed design. The data is then compared with previously designed helmets, and conclusions are drawn based on the outcomes.

Methodology

Design Process

The design of the industrial safety helmet using Fusion 360 software. Fusion 360 allowed to create a 3D model of the helmet's outer shell and foam lining. The helmet had an extra layer of protection on the upper section, which provides support to the whole structure of the helmet, enhancing the impact absorption capability. Also, it had breathable suspensions with an open frame design for better air flow, and adjustable venting in the side of the helmet to enhance user comfort. Designing an industrial helmet on Fusion 360 can be done using the following process and the final design is shown in (Figure 1).

a) Research and concept development: Begin by researching different types of industrial helmets and their features. Determine the specific requirements for the helmet you want to design, such as its primary use, safety standards, materials, and ergonomics. Sketch out different concepts for the helmet based on your research.

b) Create a basic shape: Start by creating a basic shape of the helmet using the appropriate tools in Fusion 360. Draw the profile of the helmet using sketches and then extrude it to create a three-dimensional shape.

c) Add features: Once you have the basic shape, add features such as ventilation holes, chin straps, ear protection, and other functional elements that you determined in your research and concept development.

d) Refine the shape: Use the sculpting tools in Fusion 360 to refine the shape of the helmet and ensure that it fits comfortably on the head while providing adequate protection.

e) Test and iterate: Once you have a complete design, use simulation tools to test the helmet's strength and durability. Make any necessary adjustments and test again until you are confident that the product meets safety standards and performs as expected.

f) Finalize design: Once you have completed all necessary tests and made any final adjustments, finalize the design by adding any branding or aesthetic elements.

g) Document and manufacture: Finally, document the design and create technical drawings, bill of materials, and assembly instructions. The helmet can then be manufactured using a variety of methods, such as injection molding or 3D printing (Figure 1).

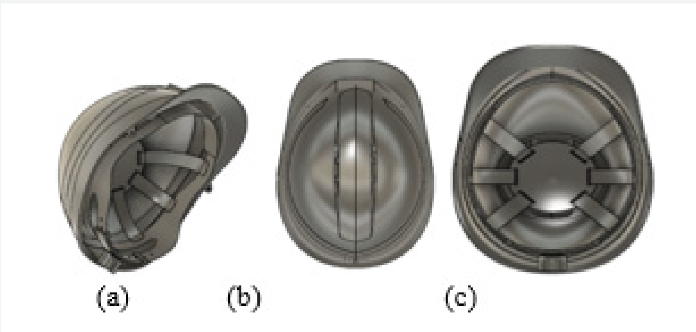

Figure 1: Proposed helmet design (a) Isometric view (b) Top view (c) Bottom view.

Boundary Conditions

To test the effectiveness of the designed helmet, a stress simulation experiments was conducted using Polycarbonate (PC), High Density Poly Ethelene (HDPE), and Acrylonitrile Butadiene Styrene (ABS) materials using Fusion 360 software. The design was subjected each material to an impact force of various quantity (in KN), simulating a falling object hitting the helmet. The maximum stress and deformation values were recorded for each material under the same impact conditions, and the results were compared to determine the most suitable material for the helmet.

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Data Collection

A collected data on the maximum stress and deformation values of each material during the stress simulation experiments was noted down. The data was collected using Fusion 360 software, and a record of the results for each material in a spreadsheet is obtained for analysis.

The process of data collection for industrial safety helmets can involve several steps depending on the purpose and context of the data collection. Here are some common steps that may be involved:

Identify the objective

1. Determine the scope
2. Select the data collection method resources.
3. Develop data collection instruments
4. Collect the data
5. Clean and analyze the data
6. Interpret and report the findings

Data Analysis

The next step is to analyze the data obtained from the stress simulation experiments using statistical methods to determine the most suitable material for the helmet design. Then the values are compared for the maximum stress and deformation values of each material and selected the one that offered superior impact absorption capability.

Results and Discussions

To identify the results various materials such as HDPE, ABS and PC were considered and shown in various tables. The analysis involved subjecting the materials to different forces, including 300, 450, 500, and 1000N. Parameters such as von-Mises stress, displacement, reaction force, and factor of safety for each material have been calculated. (Table 1-4) shows the material behaviour at the load of 300, 450, 550 and 1000 N respectively. In the table 1 we can observe that PC material has shown the least von Misses stress.

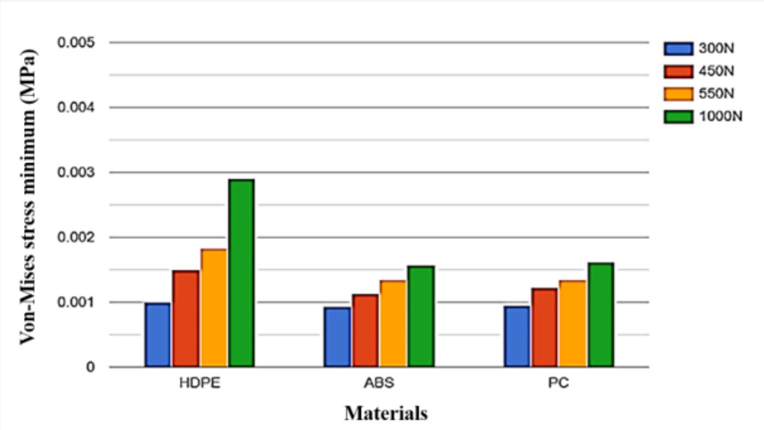

Figure 2: Minimum von Mises stress distribution on various materials.

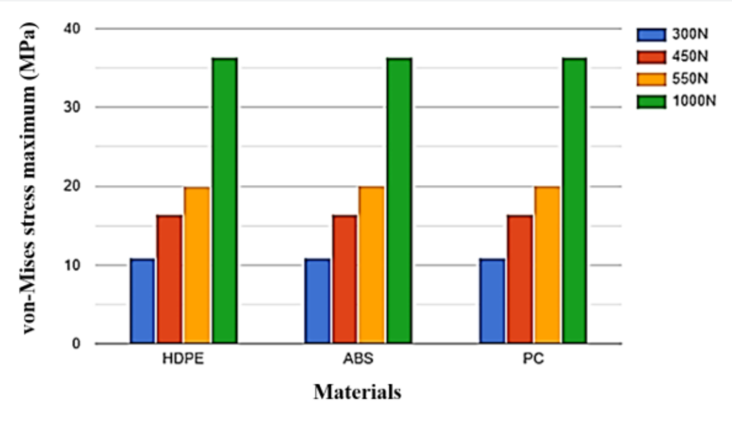

Figure 3: Maximum von Mises stress distribution on various materials.

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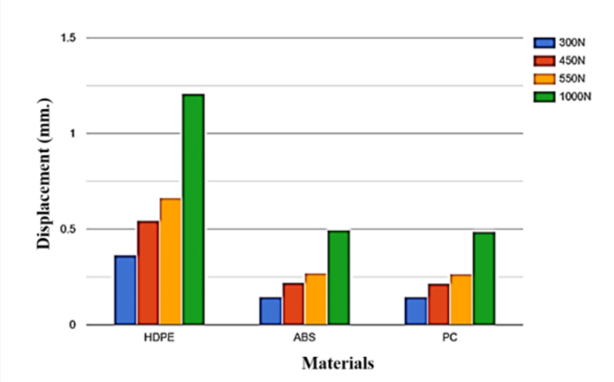

Figure 4: Displacement of stress on various materials.

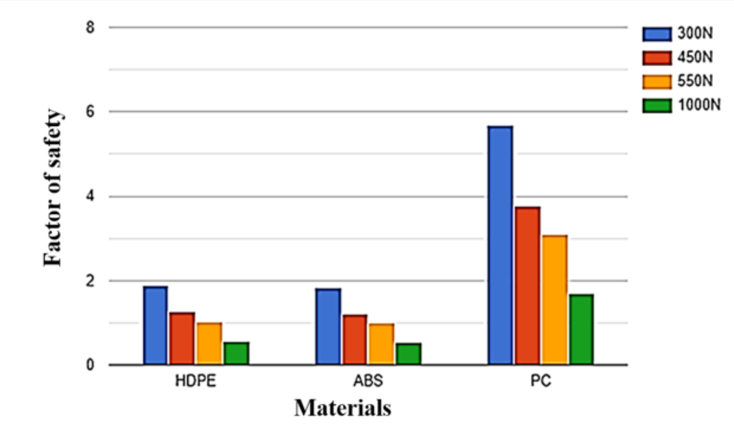

Figure 5: Effect of reaction forces on various materials.

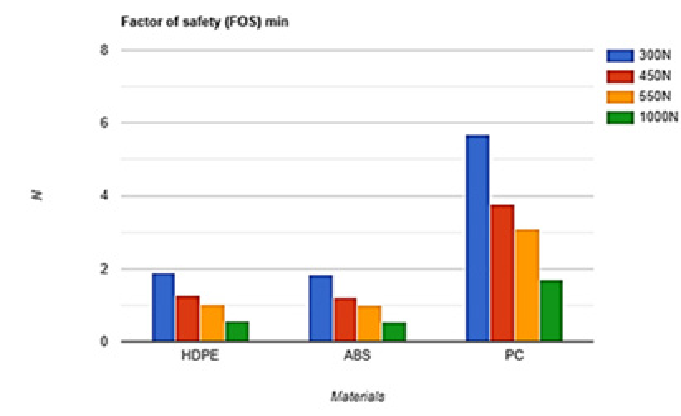

Figure 6: Factor of safety of various materials.

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(Table 1-4), (Figure 2-6).

Table 1: Material behaviour comparison under 300N load.

Material	von-Mises Stress Minimum / Maximum (MPa)	Displacement (mm)	Reaction Force	Factor of Safety (FOS)
HDPE	0.001005 || 10.91	0.3628	35.6	1.894
ABS	0.000932 || 10.93	0.1483	34.94	1.83
PC	0.0009588 || 10.93	0.146	34.96	5.672

Table 2: Material behaviour comparison under 450N load.

Material	von-Mises Stress Minimum / Maximum (MPa)	Displacement (mm)	Reaction Force	Factor of Safety (FOS)
HDPE	0.001507 || 16.37	0.5441	53.33	1.263
ABS	0.001133 || 16.39	0.2224	52.34	1.22
PC	0.001227 || 16.39	0.219	52.36	3.782

Table 3: Material behaviour comparison under 550N load.

Material	von-Mises Stress Minimum / Maximum (MPa)	Displacement (mm)	Reaction Force	Factor of Safety (FOS)
HDPE	0.001833 || 20	0.665	65.16	1.033
ABS	0.001356 || 20.03	0.2718	63.94	0.9983
PC	0.001342 || 20.04	0.2676	63.96	3.095

Table 4: Material behaviour comparison under 1000N load.

Material	von-Mises Stress Minimum / Maximum (MPa)	Displacement (mm)	Reaction Force	Factor of Safety (FOS)
HDPE	0.002909 || 36.36	1.209	118.4	0.568
ABS	0.001578 || 36.42	0.4941	116.1	0.5491
PC	0.001624 || 36.42	0.4865	116.2	1.703

From (Table 1-4) we have found that polycarbonate plastic helmets exhibit higher resistance against external loads and produce less displacement and volumetric strain than ABS plastic helmets. The results indicate that polycarbonate plastic has a higher withstanding capacity, and its rigidity provides better protection to the wearer's neck against impact loads. Polycarbonate (PC) plastic has been found to be superior to ABS material for helmet designs. Analysis of external loads, displacement, and volumetric strain indicate that PC can better withstand impact loads and provide greater rigidity to the human neck as reflected in (Figure 2-6) In comparison to composite materials like HDPE and ABS, PC material met safety standards set by various departments across the country. The design has been validated to comply with the Indian Standard Code of Practice for Industrial Safety Helmets (IS 2925:1984) and European standard code of practice (EN 397), ensuring shock absorption, vertical penetration resistance, flame resistance, and chin strap attachment strength. The design includes earmuff and chin strap attachment points that meet all relevant specifications. The helmet's two main components are a hard outer protective shell and an inner harness, providing adequate protection against head injuries caused by falling objects, impact, and penetration. Overall, adherence to safety standards and detailed analysis have led to the selection of PC material for the helmet design due to its superior performance characteristics compared to other materials. The results of the analysis showed that polycarbonate performed the best under these various force circumstances.

After conducting extensive research and analysis, it can be concluded that the helmet design and materials utilized have successfully met the required industrial standards. The efficacy of the helmet was evaluated using the fusion 360 software, which allowed for the measurement of displacement and stress capabilities. The results obtained from the analysis indicate that the polycarbonate (PC) material utilized in the helmet design performed exceptionally well and was on par with the required standards. In comparison to other materials such as polyethylene, HDPE, and ABS, the polycarbonate material demonstrated superior performance with regards to stress capability and displacement. Furthermore, the displacement values recorded

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in the polycarbonate helmet were significantly less than those recorded in the HDPE and ABS helmets, which showed greater displacement. This suggests that the polycarbonate helmet design is more effective in minimizing the impact of a collision or accident, thereby ensuring better safety for the wearer. Apart from the technical performance, the design of the helmet was also considered for comfort and ease of wear. The helmet was designed with proper breathability to ensure that the wearer does not feel suffocated or uncomfortable while wearing it for an extended period.

Conclusion

In conclusion, the design and materials used in the helmet have been carefully selected and tested to ensure that they meet the necessary safety and performance standards. The polycarbonate material has been shown to be highly effective in minimizing the impact of a collision, and the helmet has been designed with the utmost comfort in mind. Overall, the designed helmet is a reliable and effective safety gear that can be used in various industrial and outdoor settings to ensure maximum protection for the wearer. Also, our helmet contributes to the ongoing effort to improve industrial safety equipment and reduce workplace accidents. The findings of our analysis can be used to inform future research and development efforts in this field. The use of polycarbonate and composite materials in helmet design has the potential to save lives and reduce injuries in industries such as construction, mining, and manufacturing.

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