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Assessment of Motorcycle Helmet Potential Across Diverse Impact Directions by Means of Simulation Approach

S. Irfan Sadaq [1,*], V. Suvarna Kumar [2], S. Shahar Banu [3], Hanumantu Krishna Murty Dora [4]

Abstract

To make sure motorcycle helmets are protecting riders effectively, it is essential to analyze their performance under various impact orientations and varying speeds. Analyzing materials like ABS, PVC and GFRP gives important information about how durable and impact-absorbing they are. Ansys Finite Element Analysis (FEA) functionality enables a thorough investigation of the stress distribution inside the helmet construction under various impact scenarios. The present work is to study the behavior of the helmet under various impact directions and to study the suitable material to fabricate helmet. Through the process of modelling hits at different angles and speeds, engineers are able to evaluate the helmet's ability to withstand forces and reduce the risk of head injuries. Examining impact directions at 50 KMPH, 60 KMPH, and 70 KMPH from the front, right side, at 45^O from left, right and rear, offers a thorough assessment of the helmet's performance in practical situations. This comprehensive analysis aids in improving rider safety through helmet design and material selection optimization. All things considered, this strategy makes a substantial contribution to the ongoing advancement of motorcycle helmet technology, which eventually lowers the risk of brain injuries in auto accidents. From the results it is observed that GFRP material shows better performance compare to other materials. The impact direction top and rear are more vulnerable than other impact direction.

Keywords: Helmet, FEA (finite element analysis), speed, impact direction, GFRP (glass fiber reinforced polymer)

INTRODUCTION

A cutting-edge open-face helmet design with three ventilation openings on the top of the head. Three conventional helmet designs and a prototype helmet design each had their own finite element analysis (FEA) models built (full-face, open-face, and half-face helmets). This study took into account three possible ventilation slot widths, namely 8, 14, and 18 mm, when simulating the suggested open-face helmet. The headform acceleration caused by the half-face helmet was the highest, according to the simulation results, of all the helmet designs (303 G). The peak acceleration produced by the internal ventilation helmet was less than that of the full-face helmet[1]. LS-DYNA finite element analysis is used to examine the structural performance of commercial motorcycle helmets in Thailand for the prevention of head injuries. The structural model of the helmet was first verified under impact analysis by contrast with the test conducted in accordance with TIS 369-2557 standard. According to the results of the finite element analysis, the difference in maximum acceleration was only 4.8%. Then, using simulations of three accident situations with varying impact angles and speeds, the protective effectiveness of the helmet structure was examined.

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In order to determine the structural strength, energy absorption, HIC, and AIS were evaluated. High collision speeds and angles led to the worst instance, which had the greatest impact force and HIC. Additionally, it made a 100% chance of head injury possible, according to AIS 2+, which results in passenger fatalities in collisions [2]. Various aspects of riding behaviours, such as the lack of visibility and awareness, as well as speeding problems, it is possible to identify and analyse certain behavioural patterns of riders that may be contributing to motorcycle accidents. This is crucial for a thorough and comprehensive assessment of the riders' performance and behavioural characteristics related to difficulties with speeding, visibility, and awareness. Therefore, collisions caused by these problems may be prevented [3].

To identify differences in helmet performance, comparative examinations of various helmet designs are necessary. In order to assess whether newer designs offer better protection, the current study compared the impact performance of hardhat helmets, climbing-style safety helmets, and helmets with unique rotation-damping technologies [4]. Motorcycle helmets decrease mortality and morbidity, but there are no standards that say which is the safest. We wanted to know if wearing a full-face helmet decreased injuries and fatalities [5]. Investigate the factors that influence child pillion riders' use of helmets and the use of conventional helmets. In Klang, Selangor, 200 adult riders who were pillion passengers on children between the ages of 6 and 12 participated in a cross-sectional poll. It was noticed and noted how the respondents and the young passengers used their helmets properly. The use of child safety helmets was evaluated together with sociodemographic background using a questionnaire. Version 23 of SPSS was used to analyse the data. Only 3% of child pillion riders wear a conventional child safety helmet, compared to 37% of adult riders who wear a basic motorcycle helmet. Adult riders who are married, female, who always use helmets, who have higher household incomes, who travel a long distance, and who always wear helmets are more likely to use a typical motorbike helmet for its pillion passengers' kids [6].

Making helmet use a legal necessity and raising the minimum age for motorcycle operation are both prerequisites for increasing helmet use among motorcyclists [7]. In underdeveloped nations, not wearing a motorbike helmet is quite prevalent [8], despite the benefits that have been established and the required laws. There are several likely explanations for not wearing a helmet, including a lack of understanding of the factors that contribute to some motorcycle riders' lack of helmet use and unsuccessful awareness/enforcement initiatives [9]. The 6 Degrees of Freedom (6DOF) approach will be modified in this study with the intention of estimating the linear and rotational accelerations of a helmet's Center of Gravity (CoG) during an impact and assessing the method's applicability to the situation. Three hits of the helmet on a deformable structure at 8 m/s were replicated in the research using virtual testing equipment [10].

The most popular and reliable protective equipment to lessen head injuries and fatalities among powered two-wheeler riders is a motorcycle helmet. Even though their effectiveness is acknowledged on a global scale, there are still questions about how to utilise them properly for optimal head protection. In order to provide knowledge to enhance end-user helmet usage, the purpose of this systematic study is to evaluate whether aspects of helmet design and use exhibited a beneficial influence on rider safety [11]. To provide a method based on the kinematic and biomechanical head injury criteria, coupled head-helmet modelling, and analysis of a novel motorcycle helmet. The conventional drop tests were used to construct and evaluate a finite element (FE) model of a full-face motorcycle helmet [12]. A common and useful method for assessing strain, stress, and distorted sounds in GFRP (Glass Fibre-Reinforced Polymerization), Organic Fibre Composites (NFC), Carbon-Carbon, composite laminated materials, and pressure vessels with different singular, fibre briefings is to use the MATLAB programme and computational programmes like ANSYS [13,14,15,16,17,18,19].

Entire face is protected by a full-faced helmet, giving total security in the event of an accident. When operating a two-wheeler, this style of helmet shields eyes from high beam lights and dust. In this work helmet is analyzed with three different materials namely ABS, PVC and GFRP are performed at various impact directions (front, right, back, top and incline @45°) to study the behavior of the helmet similar to the work [12].

METHODOLOGY

Comprehensive motorcycle helmet used to safeguard the life of the riders was simulated using a FE analysis model, and the optimized helmet is suggested. This standard aims to lower the number of head-impact-related fatalities and injuries among motorcyclists and other road users. SolidWorks modeling software is used to model the helmet as shown in Figure 1-2 and simulation tool Ansys is used to study the performance of the same. ABS (Acrylonitrile butadiene styrene), Glass Fiber Reinforced Polymer (GFRP) and PVC (Polyvinyl Chloride) are the materials used for analyzed and studied the performance of the helmet based on their impact directions. The material properties of ABS, PV and GFRP (Glass Fiber Reinforced Polymer) are tabulated in table 1[21]. Glass / epoxy properties are based on their combination of both the materials glass fiber reinforced in epoxy resin. Parameters that effect the ability of helmet are impact directions, selection of materials, type of forces applied and at last the speed of the vehicle.

Table 1. Material Properties of ABS, PVC and GFRP.

Materials		**Youngs modulus (GPa)**		**Poisson's ratio**	**Density(kg/m^3)**
ABS		3.2		0.35	1210
PVC		2.41		0.38	1450
Glass / Epoxy @45° fiber angle					
Exx (GPa)	Eyy (GPa)	Ezz (GPa)	υ_{xy}	υ_{yz}	G_{xy} (GPa)
39.656	18.4683	18.4683	0.225	0.0486	9.2732

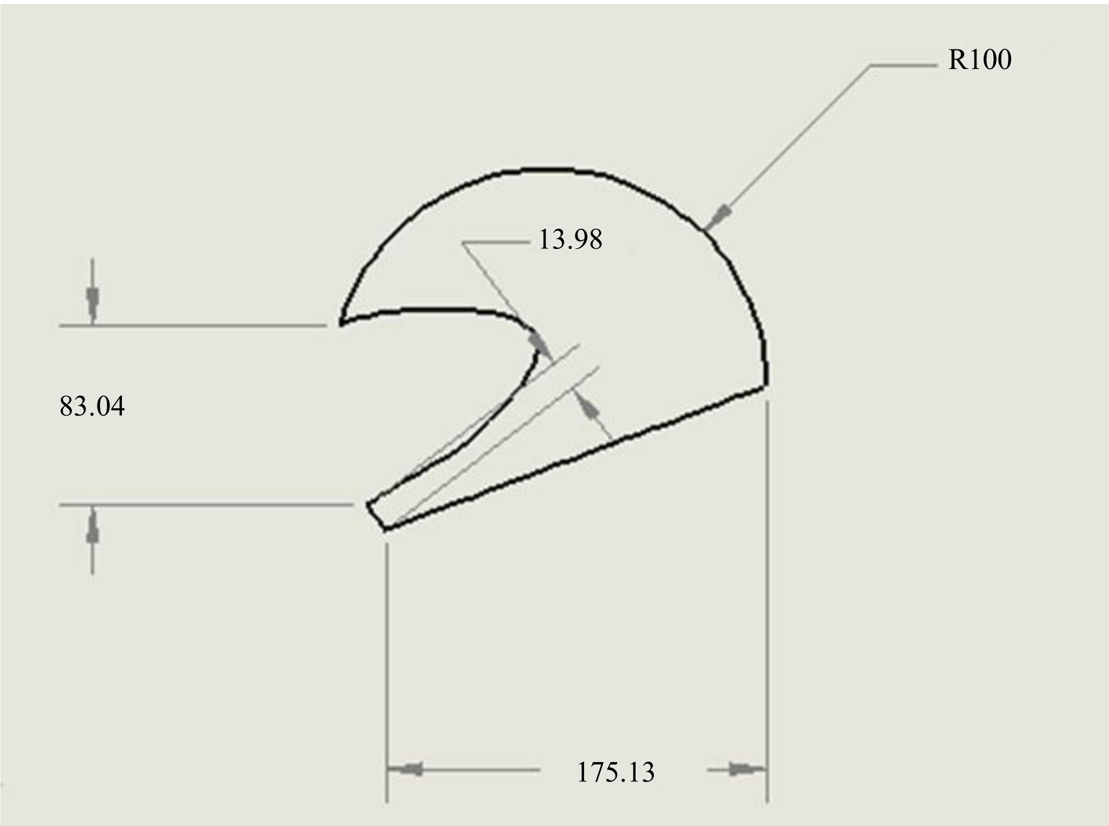

Figure 1. Dimensions of the helmet.

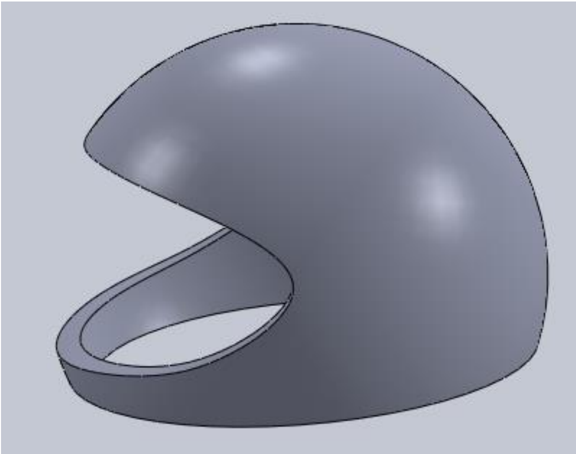

Figure 2. 3D model of helmet.

FINITE ELEMENT ANALYSIS OF HELMET

The helmet is subjected to an impact analysis utilizing the Ansys software. SolidWorks software is used to prepare the helmet model, which is then imported into Ansys programme for analysis. Base of the helmet is fixed in all degrees of freedom and the drop test at various velocity magnitude 50KMPH, 60KMPH and 70KMPH are consider and are applied same on various impact direction as stated in table 1. To choose the optimum material for a helmet, analysis is done with three different materials GFRP, ABS and PVC in five distinct directions (front, right, top, back and incline 45^{o}). The geometry and meshed model of helmet is shown in Figure 3 and FE analysis is shown in Figure 4. Table 2 shows the consolidated results. As the element size reduces, the mesh quality improves (Refinement in mesh) they by improvement in the simulation results. Boundary conditions applied in the current work are, constrain the bottom of the helmet in all degrees of freedom, impact force in terms of load are applied over the helmet based on their impact direction, The static loads are considered based on the speed of the vehicle, time duration and mass of helmet.

RESULTS AND DISCUSSIONS

Finite Element (FE) analysis was used to assess the performance of motorcycle helmets at different speeds and materials. This study focusses on impact scenarios to see how different helmets handle and distribute impact forces. The study specifically looked at how the helmet responded to hits at speeds of 50, 60, and 70 km/h. The impacts were evaluated from various angles to approximate real-world collision events. These directions comprised the front, right side, back, top, and a 45-degree inclination. By considering these different impact orientations, the research hopes to cover a wide variety of probable collision angles that a rider may encounter. Figure 5 to 12 exhibit the graphic outcomes of these analyses. These graphs show how von Mises stresses, strain, and deformation change with varied speeds and impact orientations, giving a visual picture of the helmet's protective properties under diverse scenarios.

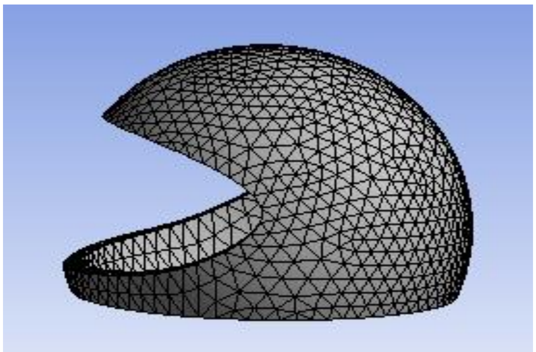

Figure 3. Geometry and meshed model of helmet.

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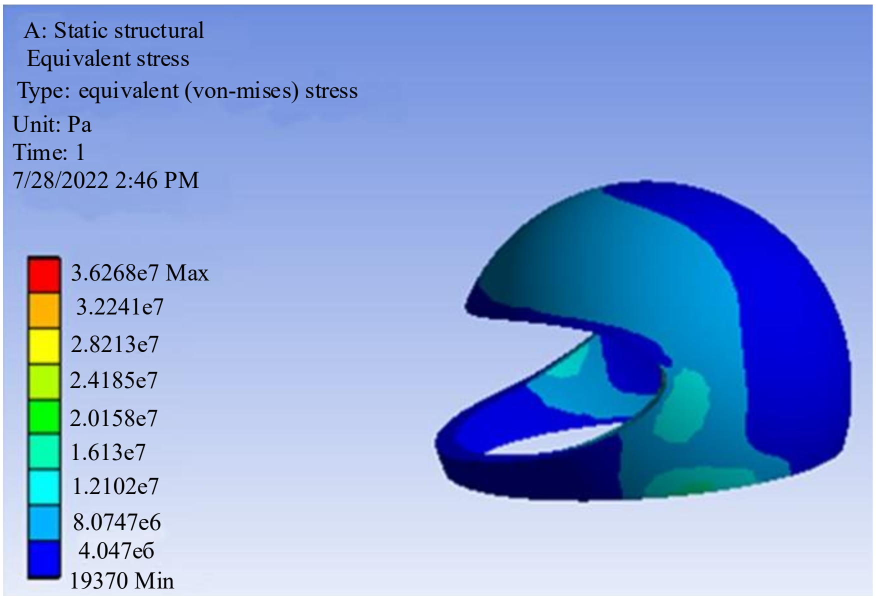

Figure 4. von Mises stress of helmet.

Table 2. FE analysis of the helmet for ABS material with various impact directions and speeds.

Hitting direction	Speed (KMPH)	PVC von mises stress (MPa)	ABS von mises stress (MPa)	GFRP von mises stress (MPa)	PVC von mises strain	ABS von mises strain	GFRP von mises strain	PVC deformation (mm)	ABS deformation (mm)	GFRP deformation (mm)
Front	50	36.069	31.132	64.733	0.008	0.007	0.015	0.464	0.465	0.232
	60	42.688	34.121	72.526	0.008	0.008	0.016	0.560	0.561	0.280
	70	49.386	39.527	83.984	0.009	0.009	0.018	0.653	0.654	0.327
Right	50	40.835	38.478	78.135	0.009	0.008	0.017	0.502	0.495	0.249
	60	48.304	43.343	89.167	0.010	0.009	0.019	0.607	0.599	0.302
	70	50.335	44.637	92.123	0.010	0.008	0.017	0.711	0.720	0.358
Back	50	46.698	46.693	93.389	0.011	0.010	0.021	0.465	0.465	0.233
	60	53.773	53.763	107.531	0.012	0.011	0.023	0.560	0.559	0.280
	70	58.208	58.205	116.412	0.013	0.012	0.025	0.657	0.655	0.328
Top	50	43.767	51.421	99.015	0.014	0.011	0.024	0.628	0.749	0.344
	60	51.039	49.057	99.105	0.014	0.012	0.024	0.759	0.900	0.415
	70	54.272	51.410	104.251	0.014	0.012	0.024	0.889	0.581	0.368
Inclined @45°	50	42.586	45.232	89.141	0.013	0.013	0.026	0.516	0.623	0.285
	60	48.553	52.406	102.885	0.014	0.012	0.026	0.622	0.727	0.337
	70	51.421	56.240	110.070	0.014	0.013	0.026	0.726	0.550	0.319

Figure 5 and Figure 6 demonstrate that the impact loads on helmets increase with speed. Specifically, tensions observed at 70 km/h are greater than those recorded at 50 km/h. Among the several helmet materials examined, the Glass Fibre Reinforced Polymer (GFRP) helmet has higher stress levels than both ABS (Acrylonitrile Butadiene Styrene) and PVC (Polyvinyl Chloride). This suggests that GFRP helmets withstand more stress upon impact than ABS and PVC helmets. An important finding is that increased stress levels in the helmet are associated with less impact force conveyed to the human skull. As a result, for blows from the front and right sides, GFRP emerges as the most effective material for providing protection and reducing harm. In contrast, for rear hits, the stress levels in PVC and ABS helmets are about comparable, while GFRP exhibits consistently greater stress values across changing speeds, as seen in Figure 7. Furthermore, Figure 10 shows that the stress created during a rear impact direction is significantly larger, with a percentage difference of nearly 20% when compared to the other four impact orientations. Remarkably, the impact loads on the top of the helmet vary minimally when compared to the rear impact direction. This shows that, while the top impact direction has lower stress levels, it is still important and can compromise rider safety.

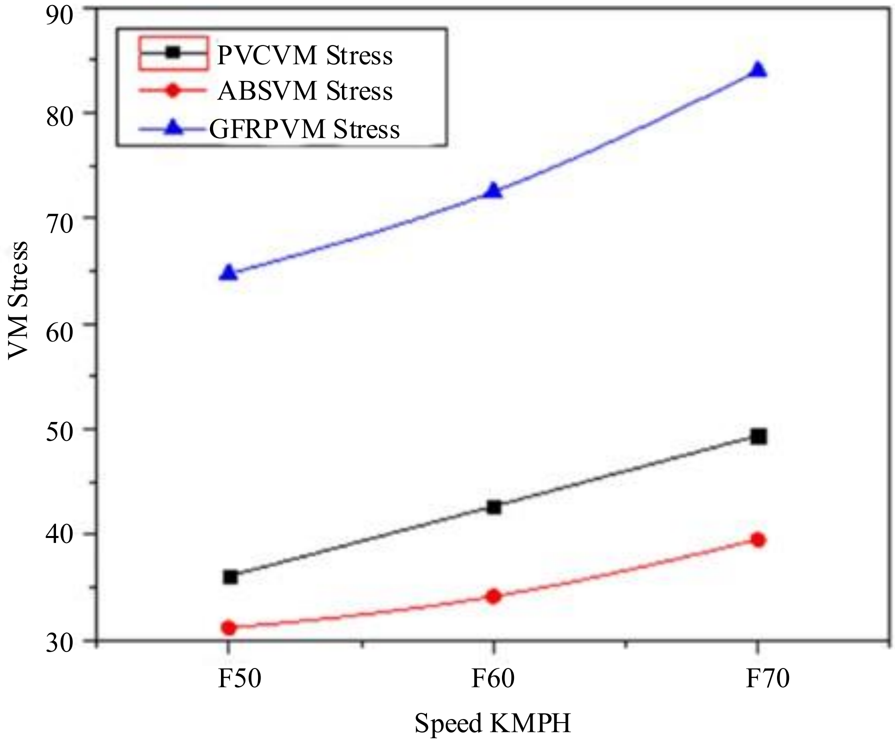

Figure 5. von Mises stresses of helmet at variable speeds from front direction.

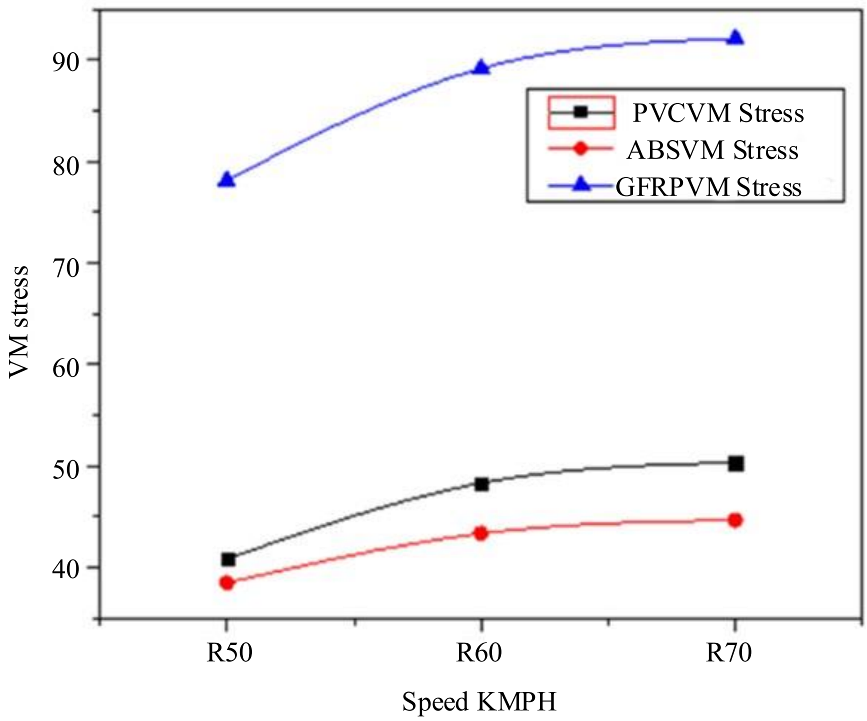

Figure 6. von Mises stresses of helmet at variable speeds from right direction.

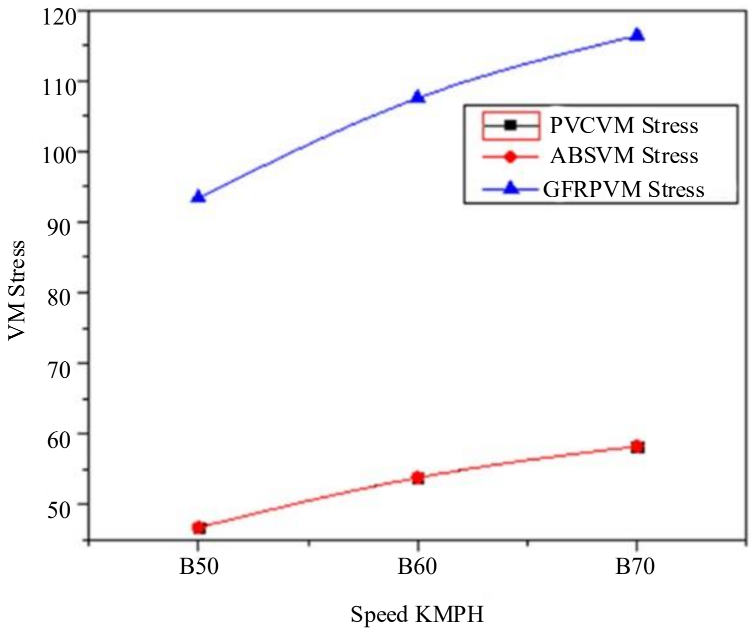

Figure 7. von Mises stresses of helmet at variable speeds from back direction.

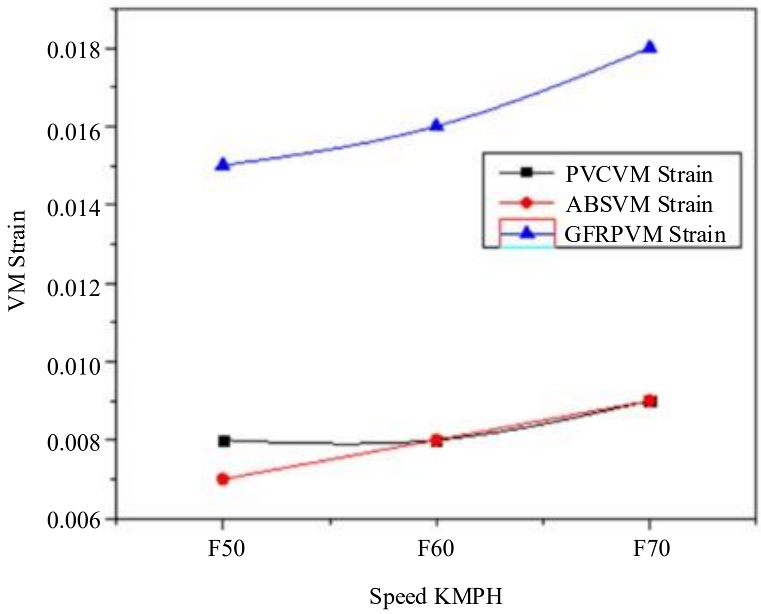

Figure 8. von Mises strain of helmet at variable speeds from front direction.

According to Figure 8, the strain encountered by the ABS material helmet is rather minimal when struck at a speed of 50 KMPH. As the speed increases, the tension levels off and stabilises at 70 KMPH. In contrast, the GFRP material shows a larger strain than both ABS and PVC materials, indicating that GFRP is more affected by increased impact speeds. The strain values for ABS and PVC helmets are essentially same across different speeds, with very minor variations as the speed increases. When investigating varied speeds and impact directions, it is clear that both ABS and PVC materials retain a consistent strain rate of 70 KMPH for front-facing hits. This tendency is consistent across other impact directions, as seen in Figure 12. This homogeneity in strain response across multiple speeds and impact orientations indicates that ABS and PVC materials operate predictably and consistently under varied impact circumstances.

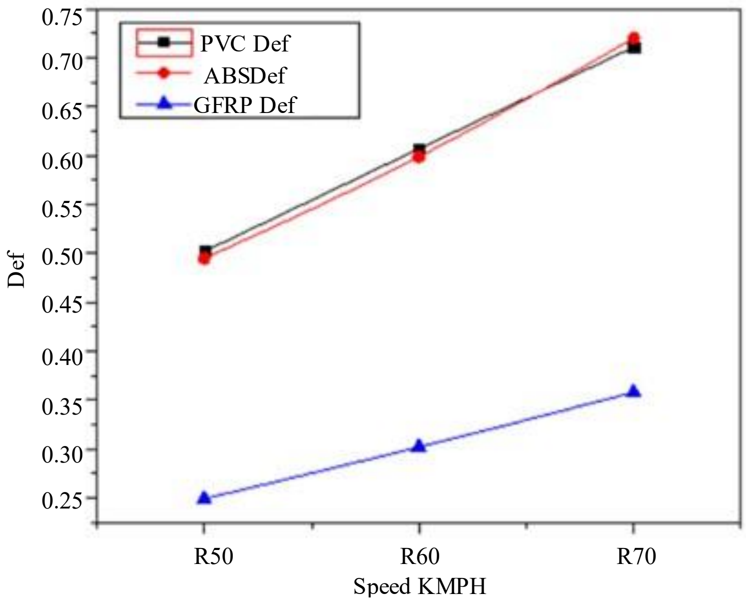

Figure 9. Deformation of helmet at variable speeds from right direction.

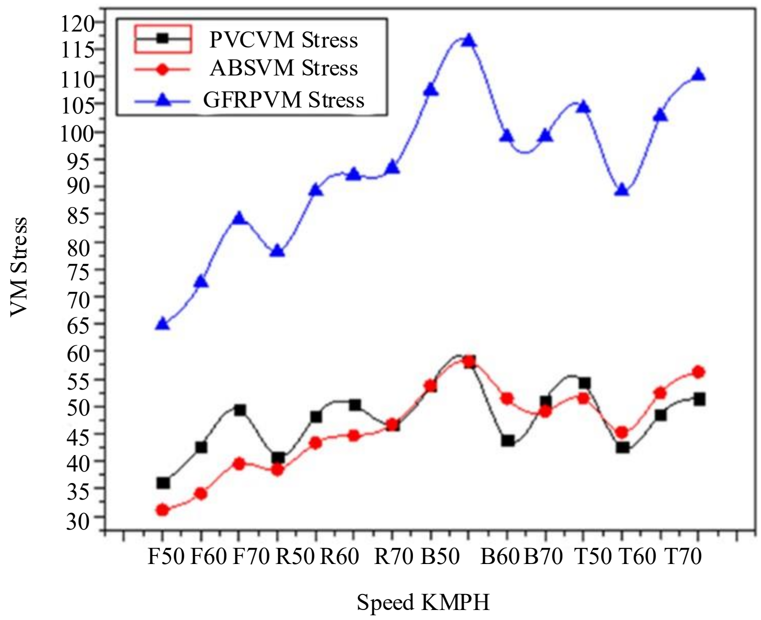

Figure 10. von Mises Stress of helmet for five impact directions at variable speeds.

Figure 9 indicates that GFRP material has lower deformation than ABS and PVC materials. Furthermore, the distortion measurements for ABS and PVC helmets are almost comparable at all accelerations, with less than a 1% difference as speed increases. Regardless of speed or impact orientation, GFRP substance consistently displays the least distortion in all five impact directions.

The best method to avoid major head injuries is to compare the von Mises stress, strain, and deformation of GFRP, ABS, and PVC materials over varied collision directions, as shown in Figure 10 to 12. The von Mises stress readings for GFRP reinforced with epoxy resin are higher than those for other materials over other directions. This suggests that collisions from behind put additional strain on the helmet's material, pointing to a potential weakness in damage protection. Furthermore, there is a reduced deformation during various directions of GFRP material, indicating that the helmet retains its firmness well when impacted from both the front and back, potentially providing adequate head protection. In contrast, blows across the front, top incline, and back orientations cause more deformation, implying potential impacts from the slanting right or left side represent a larger danger of collapse of the structure or ineffective head trauma mitigation. These findings suggest that head traumas should be prevented on either side of the head. Even under higher stress levels, the helmet exhibits minimal distortion in these directions, showing good energy retention and durability. Further analysis and testing are required to validate these findings and enhance helmet design.

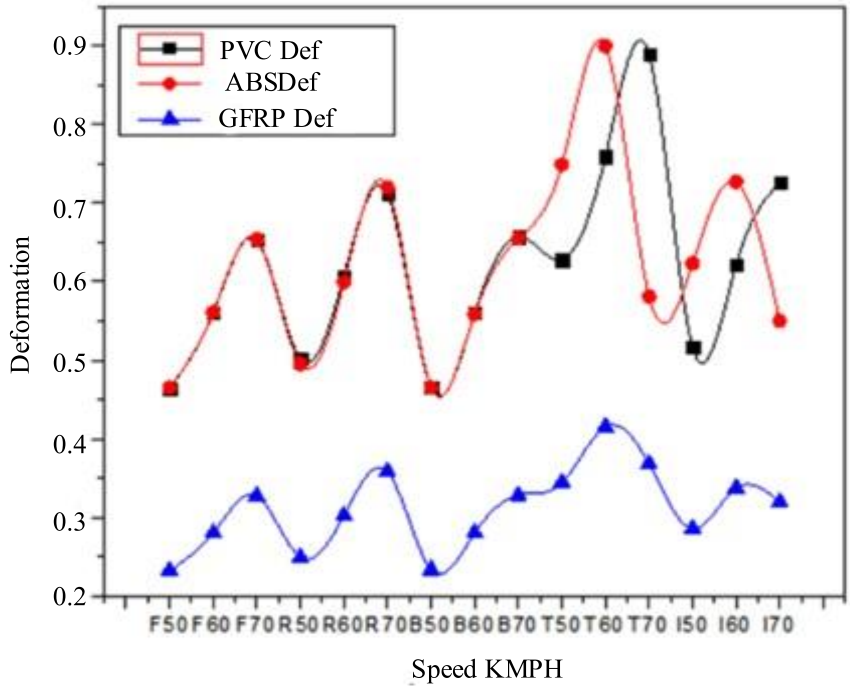

Figure 11. Deformation of helmet for five impact directions at variable speeds.

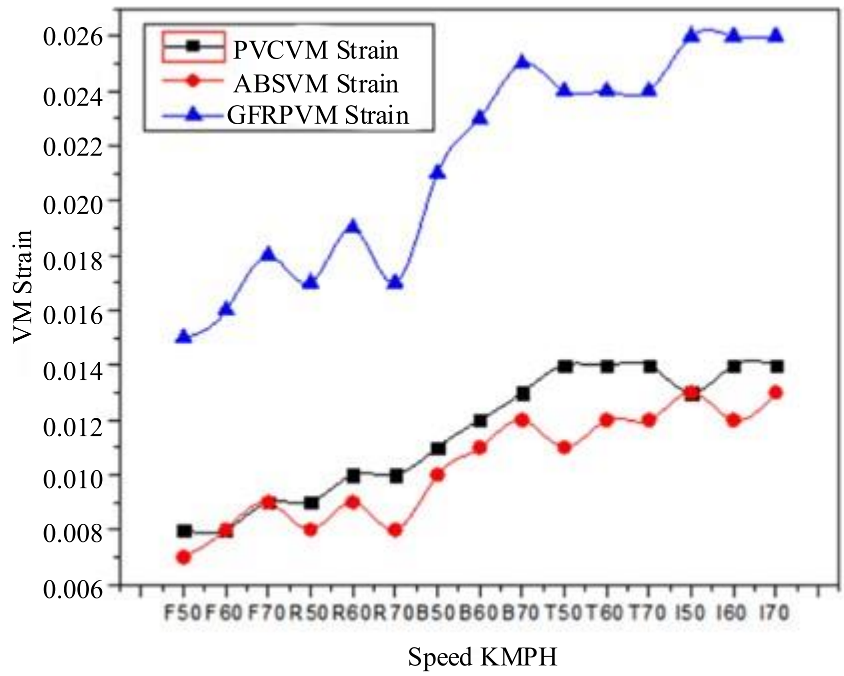

Figure 12. Strain of helmet for five impact directions at variable speeds.

GFRP typically outperforms in terms of deformation resistance, particularly at greater speeds and in a variety of impact angles. ABS is more sensitive to impact direction and speed than PVC, yielding higher deformation values as shown in Figure 13 to 14. Deformation increases with speed in all materials. PVC and ABS are increasing at a faster rate than GFRP. ABS exhibits the greatest rise in deformation with speed when impacted from above. The impact direction has a major influence on the deformation of PVC and ABS, with top and inclination impacts producing the most distortion. GFRP deformation as shown in Figure 15 is relatively steady irrespective of contact direction, demonstrating its reliable performance.

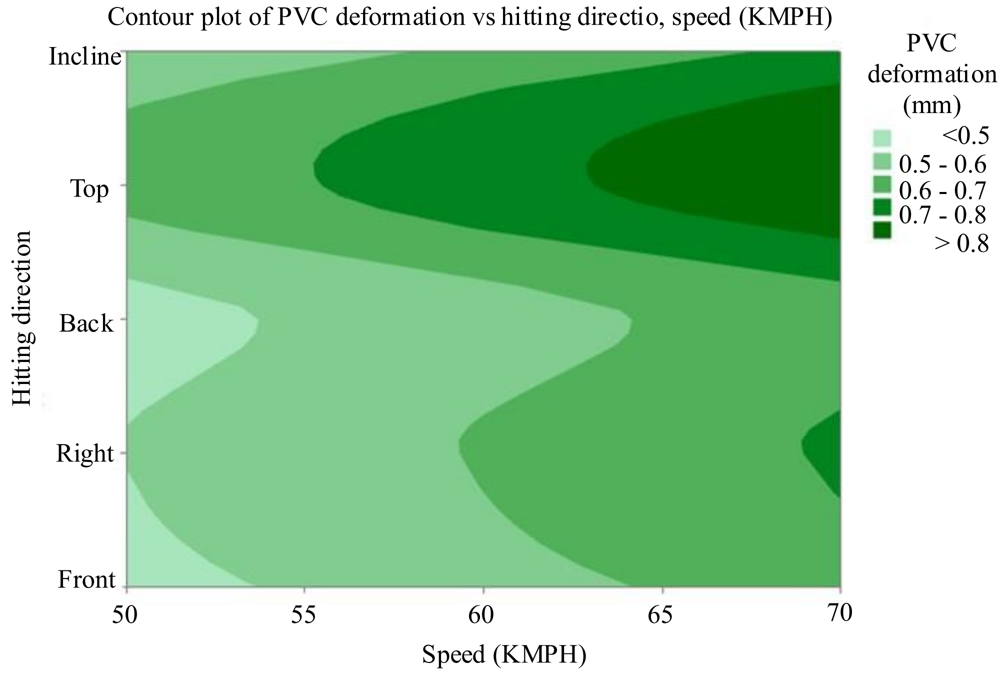

Figure 13. Deformation of helmet for five impact directions at variable speeds for PVC material.

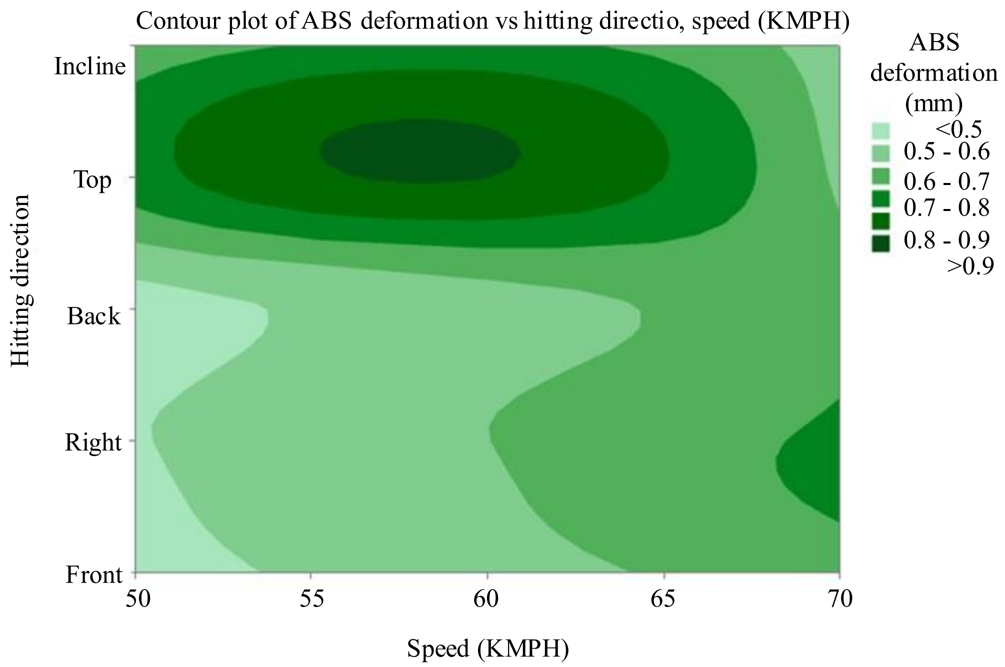

Figure 14. Deformation of helmet for five impact directions at variable speeds for ABS material.

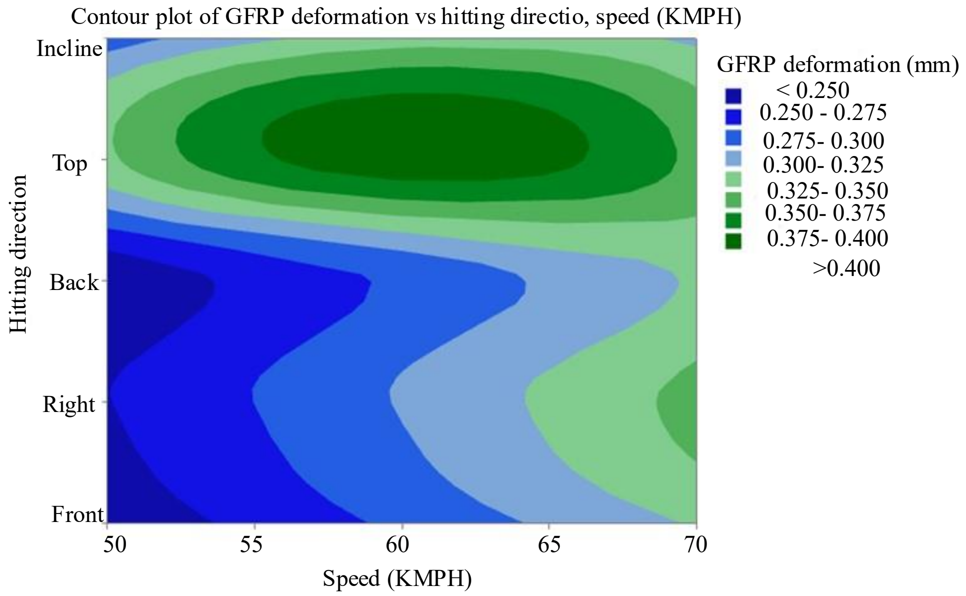

Figure 15. Deformation of helmet for five impact directions at variable speeds for GFRP material.

As stated in [12,20], ABS material has better performance. The same is observed in between the ABS and PVC materials. When ABS is compared with GFRP material helmet, GFRP shows relatively low deformation compared to PVC and ABS, with deformation increasing with impact speed. For example, at 70 KMPH, GFRP deformation is around 0.327 mm when impacted from the front, and 0.358 mm when impacted from the right. GFRP relatively consistent but slightly increases with inclined impact direction.

Similar to PVC, ABS shows a consistent increase in von Mises stress with rising speeds for all impact directions. However, the stress values are higher than those of PVC, indicating that ABS may have lower impact resistance compared to PVC. The stress values for GFRP increase more significantly with speed than for PVC and ABS. All materials show an increase in stress with speed. GFRP has the highest stress values, suggesting it experiences the most deformation under front impact. Consistently has the highest stress values, which might be due to its material properties that cause it to experience higher deformation under impact. GFRP may be suitable for applications requiring high stiffness and strength as indicated in [20,21,22,23] but might need reinforcement or design adjustments to mitigate high-stress impacts. The strength variation between GFRP helmet of present work and work from the literature is due to the model of helmet, liner in the helmet, the percentage of volume fraction of fiber and matrix along with fiber angle considered during the analysis.

As an outcome this indicate that, Speed significantly influences the stress experienced by all materials, with higher speeds leading to higher stress. The direction of impact also plays a crucial role, with back impacts being the most severe in terms of stress. Among the materials, GFRP demonstrates the best impact resistance, followed by ABS and PVC.

CONCLUSIONS

The following findings from the analysis of helmet collisions at various speeds and impacting directions offer important information on how to design and use materials for helmets that will maximize safety:

1. GFRP material helmet exhibits better values compare to PVC and ABS materials at speeds 50, 60 & 70 KMPH, demonstrating enough resilience to survive hits.
2. Nevertheless, the helmet's material breaks down at 70 KMPH, indicating the need for strengthened materials or design changes to improve safety at faster speeds.

3. ABS materials show higher stress and lower displacement values than PVC when those values are compared. Whereas GFRP shows higher strength and lower deformation when the same is compare in between the material ABS. This suggests that GFRP might be more prone to deformation during impact, which could lead to improved energy absorption capacities. GFRP has 50% higher strength than PVC material and 49.5% more than ABS material.
4. To guarantee overall efficacy in preventing head injuries, it is imperative to strike a balance between deformation and structural integrity.
5. The analysis shows that GFRP is the best material to use in helmet construction since it can absorb hits at slower speeds without losing structural integrity. The variation between the PVC and GFRP materials is about 50%. (i.e. PVC deforms 50% more than GFRP).
6. Top and back impact direction are more vulnerable where the head of the rider affect very quicky when collided with any object. No only these two directions but also all the direction i.e., front, right and incline positions are also important direction which can enhance the strength of the helmet and product injury to the rider.

In order to maximize rider safety, these conclusions emphasize the significance of taking into account both material qualities and impact dynamics in helmet design. These results can be expanded to keep improving motorcycle helmet technology and lowering the possibility of head injuries in collisions. Use of smart materials, and application of low friction layered material inside the helmet and following the various impact test using CFD and FEA along with Design of Experiments (Taguchi Method) can improve the performance of helmet.

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