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Finite element analysis of the effect of angles on impact helmet

Watcharayut Lumdoun[1)], Kunanon Sakkampang*[1)] and Jeerayut Sriamnuai[2)]

[1)]Department of Mechanical Engineering, Faculty of Industry and Technology Rajamangala University of Techonology Isan, Sakon Nakhon Campus, Sakon Nakhon 47160, Thailand
[2)]Department of Industrial Engineering, Faculty of Industry and Technology Rajamangala University of Techonology Isan, Sakon Nakhon Campus, Sakon Nakhon 47160, Thailand

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Abstract

This research examined the helmets of motorcyclists with an impact tester using a solid round hammer, 45° pointed hammerhead, serrated hammerhead, and a curved hammerhead. The weight of the hammer, 15 kg, was dropped at height 1 m (E_k = 146 J), 2 m (E_k = 294 J), 3 m (E_k = 441 J) and 4 m (E_k = 588 J), respectively, to analyze the effect of the impact load. The experimental results were comparatively analyzed using Finite Element Analysis (FEA) at angles of 55°, 70C, 80°, 90°, 100° and 110°. According to the results of this study, it was found that the curved hammerhead showed the lowest load compared to the highest loaded hammerhead, 45° pointed hammerhead, which was the highest among all hammerheads at any speed. The maximum impact load angle was 90°, and the lowest impact load angle was 55° in all cases. When the results of the experiments were compared with the results from the Finite Element Analysis (FEA) model, it was found that at an angle of 90°, the model results were similar to the results of all experiment cases. The maximum difference was 5.06 %, and the results from the angle model which gave load values closest to the 90° angle were 100° and 110° respectively.

Keywords: Impact test, Load, Finite element analysis

1. Introduction

In today's world where vehicles are a necessity in human travel, it is evident that road travel is the most important mode of transport with vehicles having the highest number of users. In Thailand, motorcycle usage is a very important aspect of the country. According to a report by Chaichan et al. [1], motorcycles are the most common type of vehicle associated with traffic fatalities in Thailand. World health organization reported in 2018 [2] that road injuries were the leading cause of death and this is ranked as the second leading cause of premature death in Thailand. When considering the causes of accidents, motorcyclists is the group that is most at risk of injury [3] because motorcyclists have a higher risk of accidents than car passengers since motorcycles are not surrounded by energy-absorbing structures like cars [4, 5]. Some studies in motorcycle accident injuries found that the impact showed that the head was the most injured [6, 7]. Therefore, a helmet is necessary to prevent accidents [8] from reducing the risk of death by about 75% [9].

When looking at the prevention of accidents that occur on the head, the findings show that there is still a need to improve the area of reducing head injuries to a higher level for the safety of future motorcyclists. Helmets are composed of important parts that are used to withstand the force of impact, namely the shell of the helmet, foam part inside the helmet, and the padding inside the helmet, which serves to provide comfort [10]. The commercial motorcycles helmets need to pass the standards such as DOT (Department of Transportation), Snell (Snell Memorial Foundation), ECE (Economic Commission for Europe). However, these standards normally test the helmets on flat and kerbstone anvil. However, the road in the real-life such as in Thailand have different types of surfaces. Therefore, this study aims to investigate the impact load capacity of motorcycle helmets with different hammer heads which represent the different surfaces that could be hit the rider heads in road accident. The results of this study could be benefits for designing motorcycles helmets to suit with various road conditions.

Moreover, limited research is currently underway focusing on a more secure user-centered customization approach. The emphasis is on helmet padding to be designed according to the shape of the head [11]. Using a Finite Element (FEA) program is another great way to simulate the impact of a helmet to confirm the results of the test because it is a cost-effective method and is widely accepted by many people [12-16]. The advantages of designing using FEA as a guide to the addition of materials to helmets are essentially designed by analyzing helmet models. The resulting value is one of the most reliable and convenient calculation methods to simulate the relationship between structure and material properties [17] before applying the material to the actual test to save on budget testing as well. In addition, analysis by the FEA program allows for a variety of analyses, such as the difference in helmet impact velocity [18], guidelines for the form of cushioning material inside the helmet [19], a description of the effects on the brain tissue level [20, 21], etc. It can be seen that the use of the FEA program is very important for the design approach of helmet insertion materials, therefore it is imperative to use the FEA methodology to assist in the analysis. In this research, it will be developed in the form of adding rubber sponge into the helmet to reduce the impact load.

*Corresponding author. Tel.: +668 8338 1696
Email address: kunanon.sa@rmuti.ac.th
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The angle of impact of a helmet is another consideration for head injuries, particularly rotational acceleration, which is another important issue in relation to damage to the human head. It directly affects the shear damage [22, 23]. According to research by Bland et al. [24], a shock test of a cyclist at an incline of 30° produced rotational acceleration, which in turn caused a high degree of rotational acceleration, leading to head injury of up to 50 %. Deck et al. [25] conducted a study of helmet impact at an angle of 45º which found that there was a 50% risk of injury from high rotational acceleration resulting in head injury. In terms of using the program to analyze the impact of the helmet at different impact angles, for example, the research by Ghajari et al. [26] presented the use of the finite element method to simulate the effects of commercially available helmets using a comparison between full-body shock and impact acting with a stand-alone head shape, it was shown that the maximum head rotational acceleration was up to 40%. Based on the above information, it was found that the angle of impact can result in head injuries. Another interesting thing is that if an accident of a motorcyclist occurs and the rider's head hits around the edge of the road or obstacles on the road, this will cause much more head damage.

As in the safety standard mentioned above, the impact tests are conducted on the flat anvil. In this research, the researcher selected a helmet that is popularly used in Thailand, full face helmets, for the impact test by simulating the characters of the impact on the roads accidents such as hitting on the rough roads or road barriers. The study was conducted using the FEA program to study the impact test model using the impact test method at heights of 1, 2, 3 and 4 meters. Then the program was used to analyze the angle of damage of the helmets in terms of load, in order to study the effect of the impact on the top of the helmet before the angle adjustment was made in the FEA program. This reduces the material-intensive testing and can be used to study the pattern of load-bearing slits from the maximum impact as well as being a guideline to develop a helmet in the future for more safety for motorcyclists.

2. Methodology

2.1 Helmet selection

In a study of different types of helmets used on the road, it was found that the most popular helmets were full-face helmets as shown in Figure 1. Figure 1(a) represents the characteristics of full-face helmets used in the test, which is a helmet with a size L (head circumference 59-60 cm), the nature of this helmet is suitable for city driving or medium-distance travel because it gives a very wide view, easy to see, convenient, and is affordable. But this type of hat has its drawbacks. There is no protection against the chin area and the wind can come back under the chin which causes dry eyes easily. The helmets used in this research were selected based on tests according to the manufacturer's standards and sold in the market. The appearance of the helmet consisted of a shell made of ABS Plastic, while the foam area inside the helmet was made of EPS Foam (Expanded Polystyrene Foam) as shown in Figure 1(b).

(a)

(b)

Figure 1 Characteristics of a full-face helmet used for testing

2.2 Impact testing machine

The impact tester used in this study was 4 m. high and was equipped with a 15 kg. Hammer head that could be adjusted to different heights then allowed to fall freely to hit the specimens at the base of the impact tester which were similar to those of Onsalung et al. [27], Junchuan and Thinvongpituk [28], Sakkampang and Thinvongpituk [29] as shown in Figure 2. The hammer head attachment could be lifted to different heights before allowing it to fall freely to impact the workpiece below at the base of the machine where a Load Cell was installed to record the reaction force that occurred during the impact of the workpiece and the hammer head. Such Load Cell can record data at a frequency of up to 10,000 values per second.

In this study, a data logger capable of performing dynamics data analysis using a GREENTECH GTDL-350 data logger was used. To record at the base of the test stand as shown in Figure 2, the hammer head was pulled up by a pulley to a height of 1 m (Kinetic Energy, E_k = 146 J), 2 m (E_k = 294 J), 3 m (E_k = 441 J) and 4 m (E_k = 588 J). The drop of the hammer was recorded by a high-speed camera with a shutter speed of 1,250 frames per second. The load cell recorded the data and sent a signal to a computer to save the results.

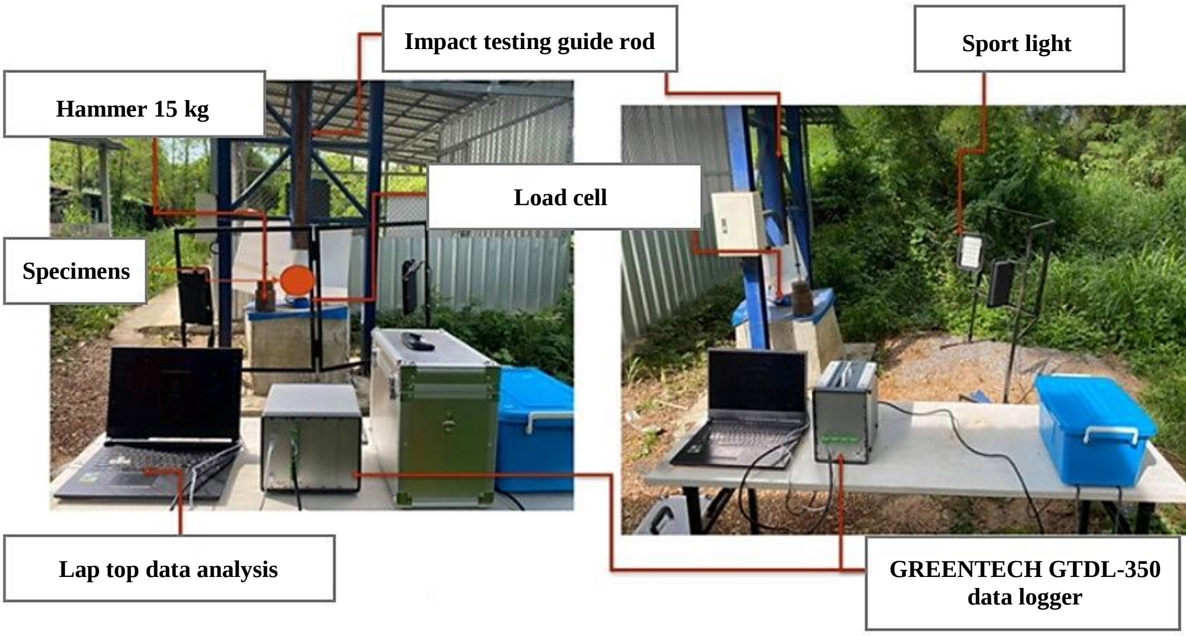
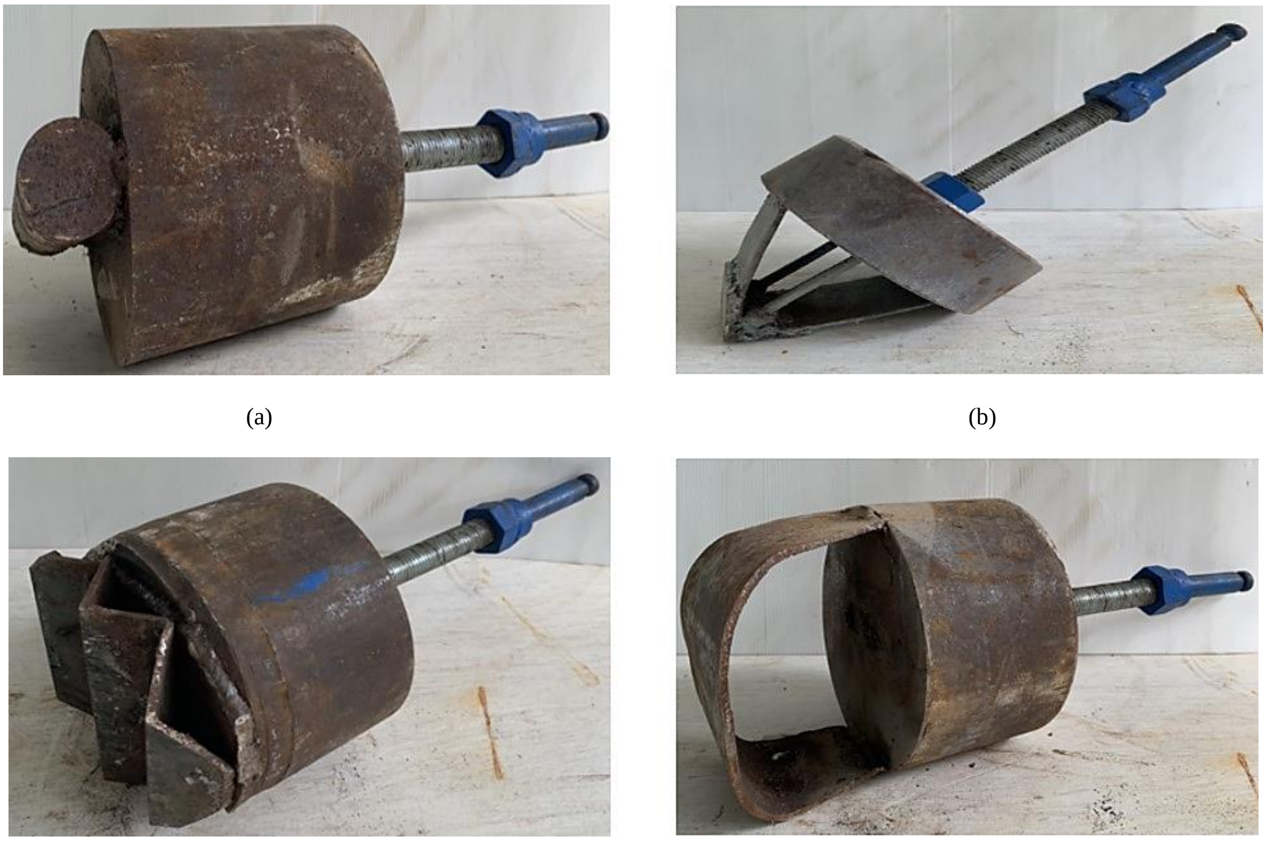


Figure 2 Impact testing machine used in the experimental study

2.3 Hammer head used for impact testing

The objective of this research was to design a hammerhead resembling a roadblock or curb. In this study, the researcher designed hammer heads divided into four types: solid round hammer (Type A), 45^{o} pointed hammer (Type B), serrated hammer (Type C), and curved hammer (Type D) as shown in Figure 3, the diameter of the hammer head was 15 cm and the researcher determined the all hammer heads to weigh 15 kg. We analyzed the impact load curve to compare whether the hammer head style characteristics yielded the greatest impact effect.



(a) (b) (c) (d)

Figure 3 Hammerhead pattern used in the test: (a) solid hammerhead (Type A) (b) pointed hammerhead 45^{o} (Type B) (c) serrated hammerhead (Type C) (d) curved hammer head (Type D)

3. Finite element model analysis

3.1 Helmet model and material properties

In the study of finite element simulations, it is essential to create a model to look like a real helmet. However, the process of modeling is done by creating a helmet by using 3d Scan to get the workpiece file as an STL file first, as shown in Figure 4. Since this file type only contains the surface of the workpiece and no inner part of the workpiece, it cannot be used for analysis by FEA methodology. Therefore, it is necessary to reconstruct the inside of the workpiece by reverse engineering (Reverse Engineering) so that the workpiece can be analyzed, and the advantage of this method is that the workpiece is the same size as the real workpiece. As shown in Figure 5, it was disassembled into a 4 mm thick shell, 27 mm thick foam on the inner side and 27 mm thick foam on the mock head used in the actual test as well. In this research, the inner fabric was not molded into the model because the results of the analysis in the program did not make much difference between the experiment and the model. The side of the hammer is made in the form of a solid round hammer with a diameter of 15 cm as shown in Figure 6.

Figure 4 3D-Scan technique to obtain a file of the helmet piece

The testing of mechanical properties of materials in this research, was performed on a prepared specimen shell made of polystyrene plastic. Acrylonitrile butadiene styrene (ABS Plastic) and rubber sponge were used to reinforce 3 types of helmets: half-face, full-face and full-face helmets. Then, the workpiece was cut according to the standard (ASTM-D638-2010). The mechanical properties test was performed by pulling the specimen at a speed of 50 mm/min. When the specimen was torn apart, the test results such as strain stress were collected. The results of the tests showed a relationship between stress and elongation of the plastic material used to make the helmet shell as shown in Table 1. It was found that the modulus of elasticity was 2.012 GPa, Poisson's ratio was 0.3 and the density was 1,200 kg/m^3. The foam padding in the helmet was made of Expanded Polystyrene Foam (EPS Foam) material and a rectangular material was prepared to test the mechanical properties of the foam by pressing the specimen with the results of the test showing the relationship between stress and workpiece elongation. In Table 2, the test shows that the specimen could bear the following loads: Maximum Compressive load was 1050.72 N, Compressive Strength was 4.20 MPa, Young's Modulus was 22.122 MPa, and Density was 150 kg/m^3.

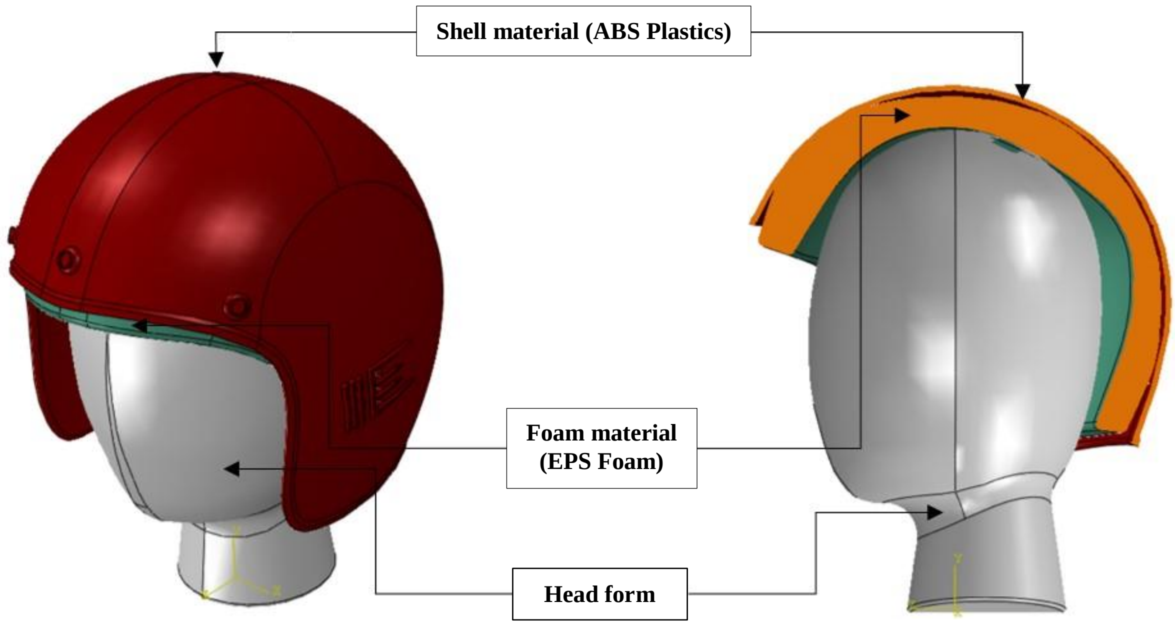


Figure 5 The model was achieved by creating the helmet used in this research

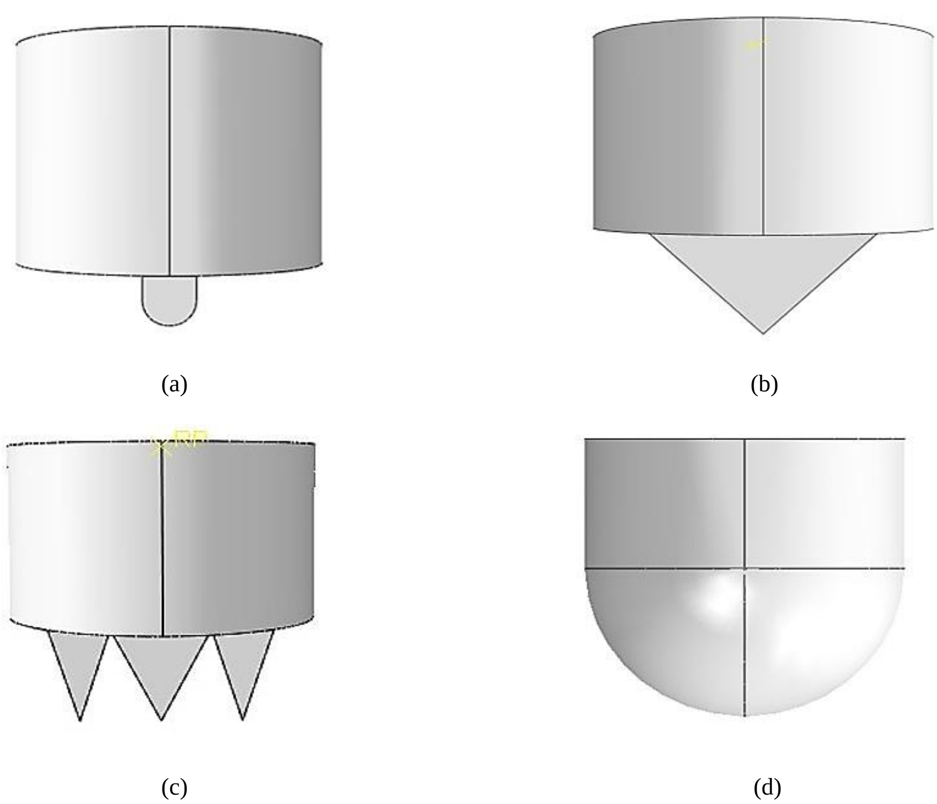


Figure 6 Research hammer head model (a) Type A (b) Type B (c) Type C (d) Type D

Table 1 Material properties of ABS plastic

Description	Value
Density (kg/m^3)	1200
Young's modulus (GPa)	2.012
Poisson's ratio	0.3

Table 2 Material properties of EPS foam

Description	Value
Density (kg/m^3)	150
Young's modulus (MPa)	22.122
Compressive strength (MPa)	4.20
Maximum compressive load (N)	1050.72
Compressive strain at break (Standard) (mm/mm)	0.936

Table 3 Mesh sizes, and number of material elements in the model.

Parts of the model	Type of material	Type of element	Size of element (m)	Number of element
Helmet shell	3D - Deformable	C3D10M	0.01	16,516
Inner foam	3D - Deformable	C3D10M	0.01	52,602
Headform	3D - Discrete rigid	R3D4	0.02	635
Hammerhead Type A	3D - Discrete rigid	R3D4	0.02	720
Hammerhead Type B	3D - Discrete rigid	R3D4	0.02	725
Hammerhead Type C	3D - Discrete rigid	R3D4	0.02	705
Hammerhead Type D	3D - Discrete rigid	R3D4	0.02	723

3.2 Finite element analysis

In the study of a helmet model where the hammer head was let to freely fall against a helmeted mock head using impact velocities of 4.42, 6.26, 7.67 and 8.85 m/s, an analysis by ABAQUS. CAE program was required to reference the pattern and nature of experiments at part laboratories. Due to the limitations in terms of impact testing machines, the impact test can only be performed on the top of the head, which here is defined as a 90°. In other angles, it is necessary to use the program to analyze. Figure 7 is a guideline for model analysis using the actual impact angle at 90°. The experiment was programmed at 90° first to compare the results with the model analysis to see if they were similar. When the graphs of the model and experimental results are similar, the angle of impact is adjusted using the analysis program. Figure 6 shows the angles analyzed in the program were 55°, 70°, 80°, 100° and 110°.Use only Garamond fonts throughout the document. If any special font is required to display the text properly, please mention this during the manuscript submission process.

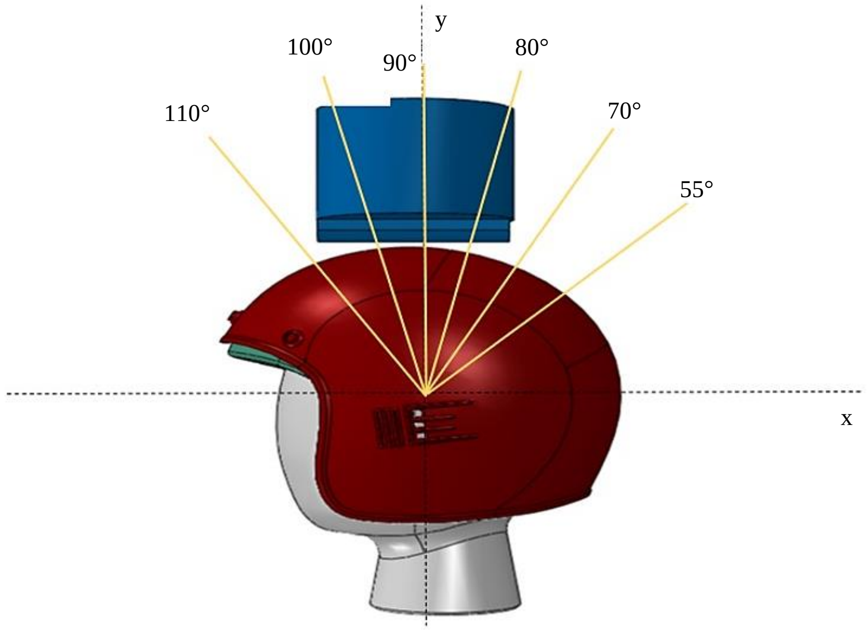


Figure 7 The impact analysis approach at various impact angles analyzed by the FEA regulations

ABAQUS.CAE program was used to analyze the model because the model analysis in this research was an analysis of an object with the velocity of impact on the material in the program called Dynamic/Explicit by requiring that the hammer head, designated as a solid (3D-Discrete Rigid), falls in the Y axis (Free U2) with a weight of 15 kg hitting a solid simulated head (3D-Discrete Rigid) wearing a helmet model where the headform is set to be motionless (U1, U3, UR1, UR2, UR3 = 0). In this study, the coefficient of contact surface friction of the specimen was 0.15 and the effect of the impact load on the underside of the simulation head at RF1 was collected as shown in Figure 8. Compared to the experiment, the RF1 point is the point where the load cell to collect the load data is placed below the specimen for the mesh characteristics and mesh sizes of the model material. The designs of the hammer head and mock head had the mesh in a 20 mm 4-node 3-D bilinear rigid quadrilateral (R3D4) pattern. In the case of the helmet shell and the foam padding, it was defined as 3D-Deformable, with a mesh pattern of 10-node modified quadratic tetrahedron (C3D10M) in all 3 materials. The mesh size of 10 mm was used. The analysis of mesh convergence can be seen in Table 3. It was found that the smaller size of mesh gave the more accurate results.

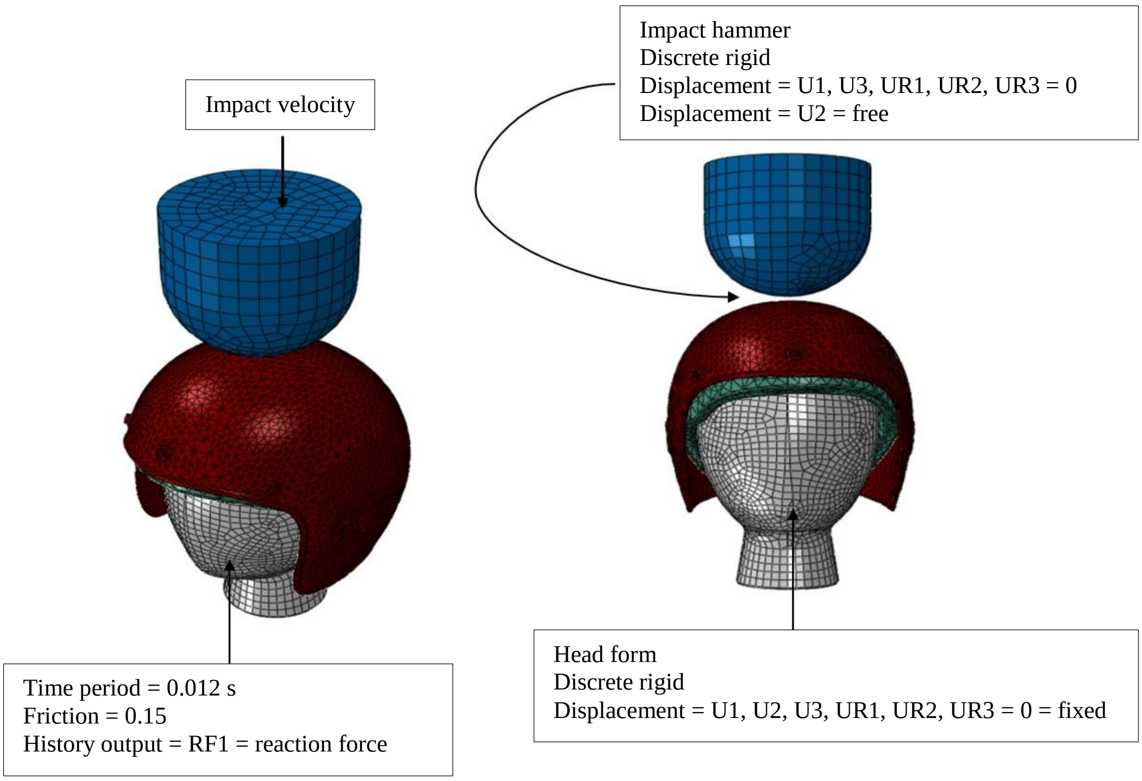
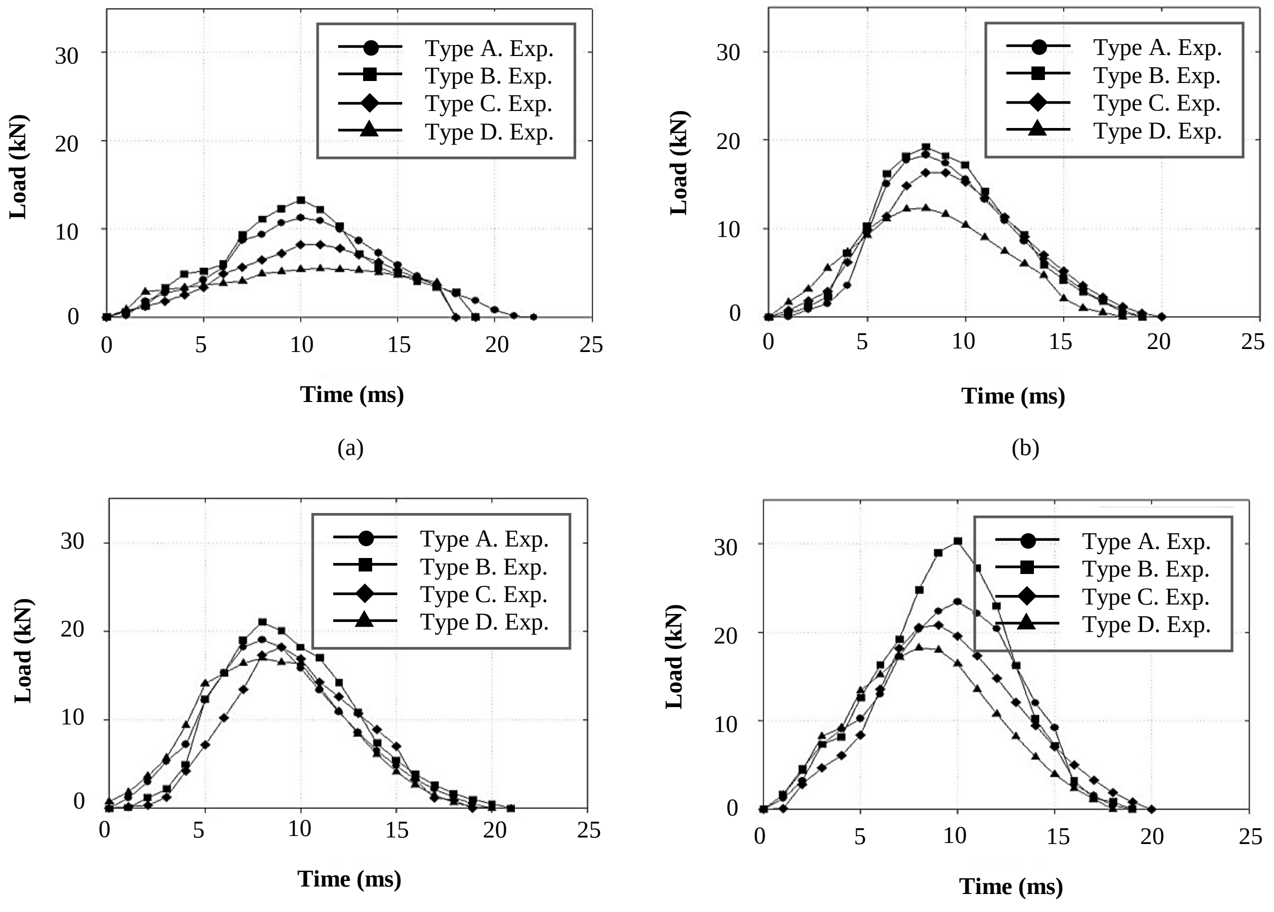


Figure 8 Conditioning in the helmet impact model by method dynamic/explicit

4. The results and discussion

4.1 Effect of load on impact at different kinetic energy levels

The study of the impact of full-face helmets using different hammer heads explored 4 different heights. From Figure 9, the graph shows the relationship between load and time of impact of various hammerhead helmets at E_k = 146 J, 294 J, 441 J and 588 J to show internal impact behavior of full-face helmets with four different hammer head designs. The graph shows the relationship between the load and time. It was found that there was a difference between the hammer heads of Type A, Type B, Type C and Type D. It was also found that the point of impact height was consistent with the reality of the impact. The conclusion is that the higher the test height, the higher the load value. From the analysis of the graphs, it was found that the graphs were consistent with the experiments of Wu et al. [30], Pinnoji and Mahajan [31] and Pinnoji et al. [32] which were mountain-like curves. In terms of the load arising from the impact, it was found that the Type B hammerhead configuration had the highest impact load in all test cases at different heights, followed by Type A, Type C, and Type D, respectively. In the case of the sample taken at E_k = 588 J, since it was the highest test height, it was found that the Type B hammer head had a maximum load of 30.28 kN, whereas Type A, Type C hammerhead, and Type D had maximum load rating of 23.40, 20.80 and 18.22 kN, respectively.



(a) (b) (c) (d)

Figure 9 The relationship between load and time of different hammerhead helmet impacts; (a) E_k = 146 J (b) E_k = 294 J, (c) E_k = 441 J, (d) E_k = 588 J

Therefore, it was analyzed that the 45° pointed hammer (Type B) would be the most dangerous in the event of a motorcycle accident when the head hits the edge of the road. For the maximum impact angle, the researcher used modeling for analysis in the program, which was discussed in the next section.

4.2 Effect of load and maximum impact load by FEA model method

In this experiment, the experimental and simulation results of the 90° impact were first compared to find out if the model was close to the experimental results after which the other angles were analyzed. Figure 10 shows the results of the finite element method model. In the first step, it was found that at an angle of 90°, both the actual test and the model analysis were approximately the same by the maximum load difference between the experimental and model analysis results. That angle was the highest at 5.62 %. In the case of Type C, at 441 J, the results of all other data formats were less than 5.62 %, which is considered an acceptable analysis result. When the results of the model and experiment were similar, the researcher changed the angle of analysis using the program. It was found that the impact angle of 90° had the greatest maximum load compared to all the impact angle. The angle of maximum load that was closest to 90° was the front of the helmet or at 110° and 100° respectively. In the analysis of the program, it was sufficient to show the tendency that impacts from the front to the top of the head carried a higher load on the head than impacts on the back of the helmet.

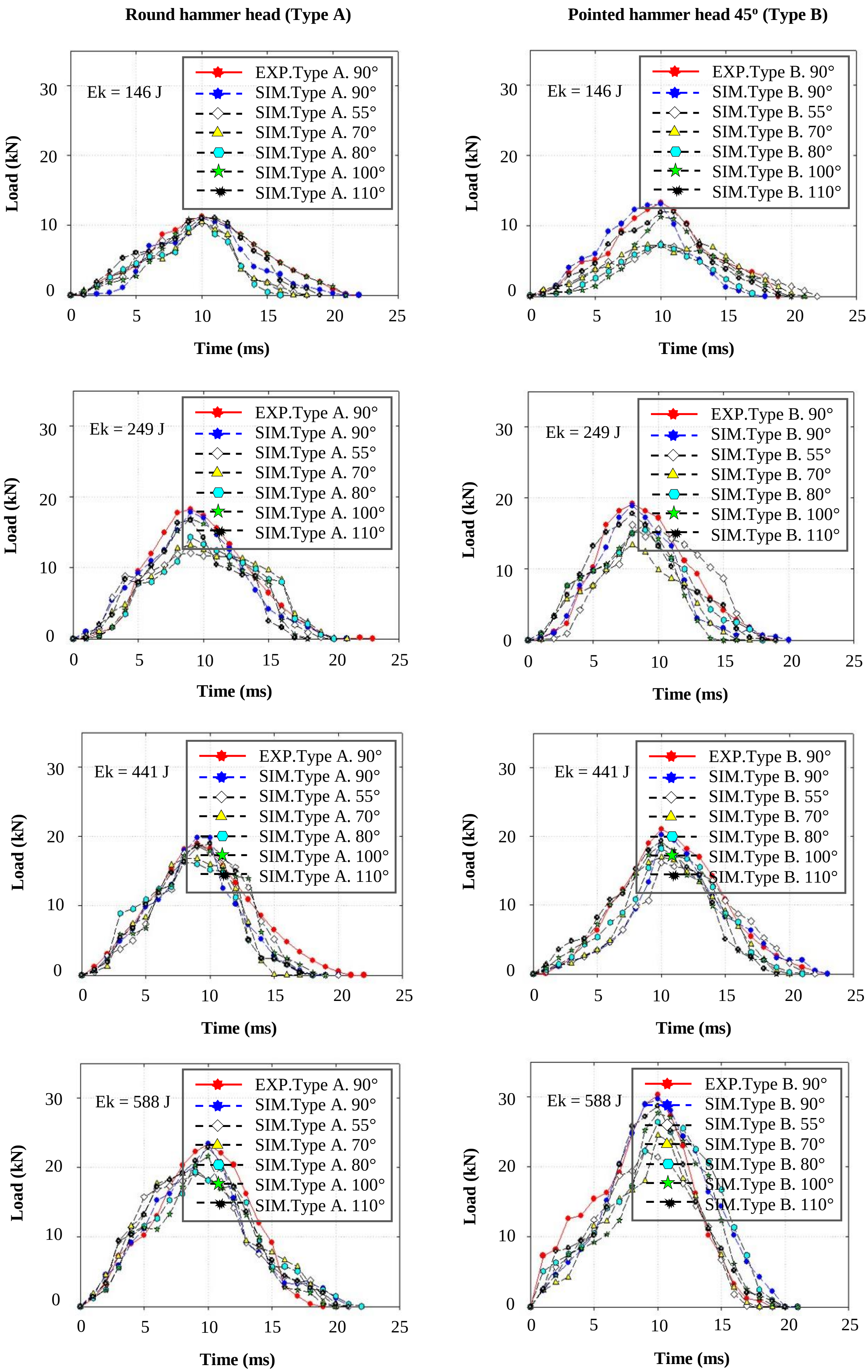


Figure 10 Analysis results of the model by finite element method at different kinetic energy levels

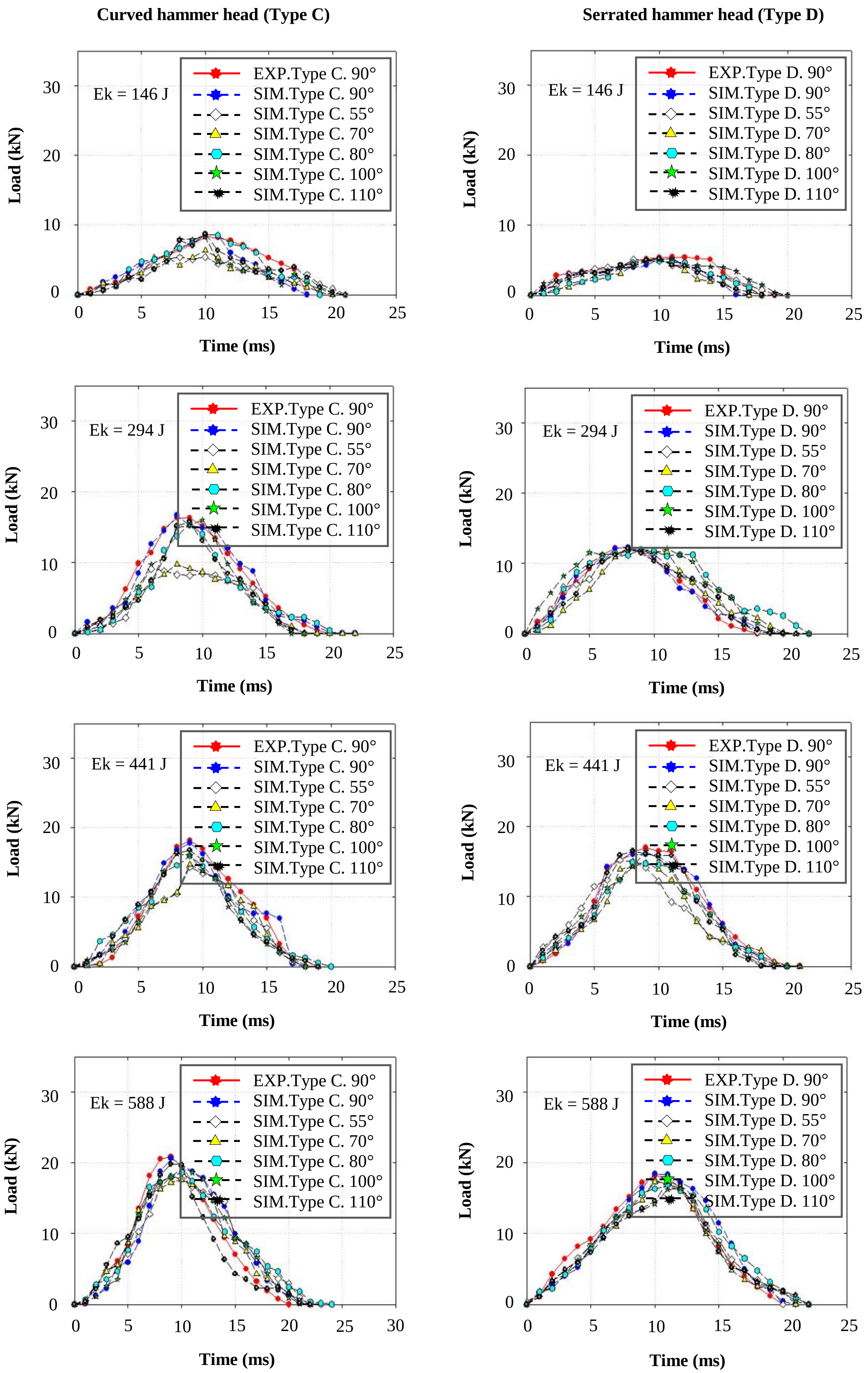


Figure 10 (Continued) Analysis results of the model by finite element method at different kinetic energy levels

In terms of the results of the analysis of the four types of hammerheads, it was found that the 45º pointed hammer head (Type B) had the highest load at any height. This was followed by the solid hammerhead (Type A), the serrated hammerhead (Type C), and the curved hammer (Type D). In the case of a model analysis at E_k = 588 J at an angle of 90º, it was found that the pointed hammer head 45º (Type B) had a maximum load of 29.72 kN. The solid round hammer head, (Type A), serrated hammer (Type C) and curved hammer (Type D) had a maximum load rating of 23.47, 20.60, and 18.45 kN, respectively. When compared with the actual test, it was found that the difference from the actual test at the same height was 1.83% (Type B), 0.28 % (Type A), 0.95 % (Type C), and 1.27% (Type D). It is therefore concluded that the experiment and the analysis by the model were approximately the same, and the impact can be analyzed at other angles and were very close to the reality.

From Table 4, the results of Figure 11 are used to analyze the maximum load that occurs in each hammer head model. It is found that the maximum load caused by the impact corresponded to the higher kinetic energy level, and the maximum load occurring at an angle of 90º. When analyzing the patterns of the hammer head hitting the helmet, it was found that the 45º pointed hammer head (Type B) had a higher load than other types at all angles of impact. Compared to Sakkampang and Thinvongpituk [29], which examined the impact on a flat anvil at a kinetic energy level of 294 J, the impact load obtained for a flat anvil was 16.82 kN. In this study at the same kinetic energy level, round hammer head (Type A) and pointed hammer head 45º (Type B) had a maximum load of 18.31 kN and 19.20 kN, which were higher than the impact on the flat anvil. In the analysis of the model, it was found that the difference between the experiment and the helmet model created using reverse engineering techniques gave much more accurate simulation results.

Table 4 The maximum load on various hammerhead helmets.

Type	E_k (J)	90º exp.	90º sim.	% Dif.	55º	70º	80º	100º	110º
Type A	146	11.27	11.03	2.10	10.32	10.54	11.09	11.09	10.98
	294	18.31	17.82	2.66	12.10	13.2	14.34	16.92	16.72
	441	19.02	19.83	4.26	18.61	16.82	16.36	18.91	18.99
	588	23.40	23.47	0.28	19.20	19.72	19.36	21.65	22.93
Type B	146	13.29	13.09	1.50	7.48	7.30	7.32	11.29	12.01
	294	19.20	18.92	1.42	16.23	13.40	15.49	16.27	17.82
	441	21.02	20.27	3.57	16.23	17.01	18.22	18.92	19.37
	588	30.28	29.72	1.83	22.30	24.53	26.43	27.69	28.73
Type C	146	8.24	8.65	5.06	5.42	6.36	8.65	8.33	8.73
	294	16.34	16.69	2.09	9.09	9.77	15.43	16.02	15.78
	441	18.20	17.82	2.10	14.30	14.74	15.96	16.22	16.78
	588	20.80	20.60	0.95	18.06	17.62	18.65	19.36	19.82
Type D	146	5.38	5.22	4.29	5.16	5.12	4.92	5.19	5.23
	294	12.30	12.31	0.02	11.94	11.79	11.96	11.90	12.15
	441	16.98	16.02	5.62	15.23	14.83	14.92	16.48	16.52
	588	18.22	18.45	1.27	17.44	17.34	16.82	16.35	17.34

Considering the impact loads of all hammer head types by analyzing the FEA model, Figure 11 shows that the impact load of 90º gave the greatest impact in all forms of hammerhead. It was also observed that the angle of impact load closest to angle 90º were angles 100º and 110º in all cases. In cases of the type B hammer impact at E_k = 588 J, since it was the hammer with the highest impact load, it was found that the maximum load value from the programmable analysis of the angle 100º and 110º were at 27.69 kN and 28.83 kN, respectively. In the case of 90º, compared to the experiment, the load was 30.28 kN. As a percentage difference in the maximum load, the difference was 8.55% in the 100º angle and 5.11 % in the 110º angle. This was considered to have a similar maximum load effect. The same as other hammerhead cases, it was found that the experimental results trended in the same direction. Considering the angle with the lowest load value from program analysis, it was found that a 55º Type B hammer angle at E_k = 588 J gave the lowest load value at 22.30 kN, whose percentage difference from the 90º trial was 26.35%, with other hammerheads tending to be in the same direction at all heights. In the case of simulation studies, it can be analyzed that the impact effect on the helmet had a high load on the front to the top of the helmet. The result of this analysis will be a guideline to analyze the angle that causes the most head injury as the impact on the front of the full-face helmet with the load value being higher than the back of the helmet, by 20 % in some cases.

4.3 Results of damage analysis by FEA model method

To determine the pattern of helmet damage by the FEA method, the current study gave an example of the damage by showing the figure of the von Mises stress. The top angle of the helmet when hit with a 45º pointed hammer (Type B), Figure 12 a simulated analysis of 90º, 100º, and 110º, the von Mises stress was 56.40 MPa. Considering the 90º angle, the stress distribution was higher than the 100º and 110º angles. The high stress nature had a greater effect on the damage done to the helmet. Comparing the studies of Mustafa et al. [33] and Mahadi [34], it was found that the prevalence of head injuries occurred in the anterior and upper extremities as well. In some studies, it was found that higher stress was found on the front of the helmet. The researchers found that each type of helmet gave different test values depending on the shape of the helmet and the material used to make the helmet. In some cases, such as the research by Teng et al. [35], helmet damage values tended to be higher in the lateral region, whereas Caserta et al. [36], where honeycomb was used to line the foam of the, found that the helmet damage and injury was high at the back of the helmet. If you consider the style of each type of helmet, it will give different results. In this study, the researcher selected the load data collection point at the nape of the mock head. This may have resulted in differences from other research as well.

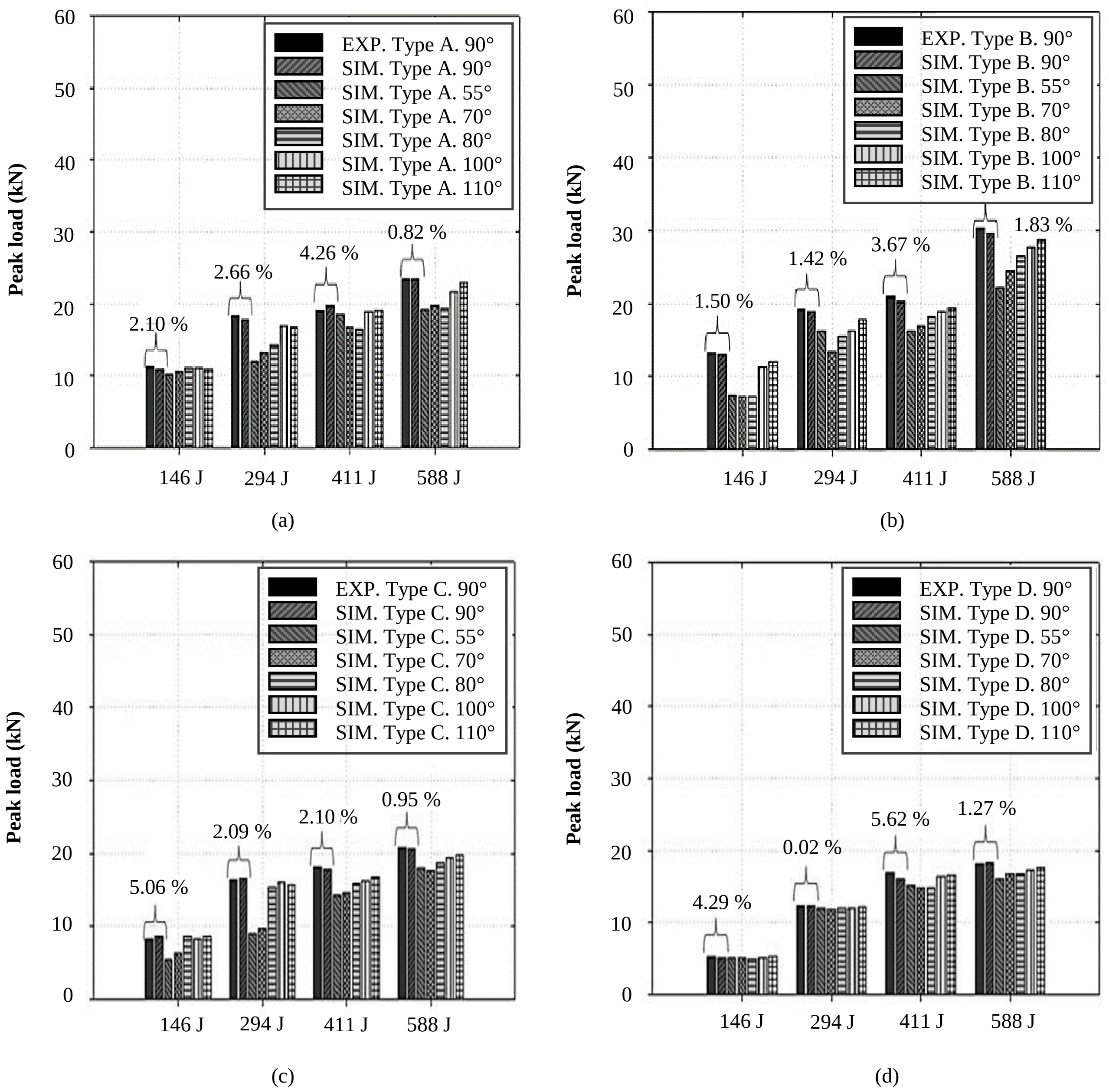


Figure 11 The graph of the maximum impact load model analysis of the four hammerheads (a) Type A, (b) Type B, (c) Type C, (d) Type D

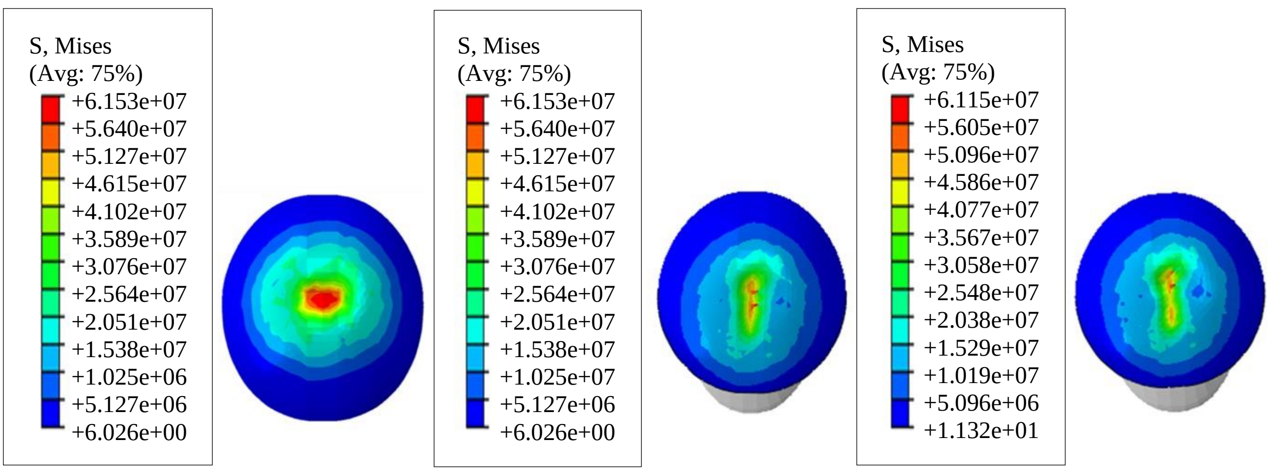


Figure 12 Effect of von Mises stress, top angle of helmet when pointed hammer head 45° (Type B), modeled at 90°, 100°, and 110° angles.

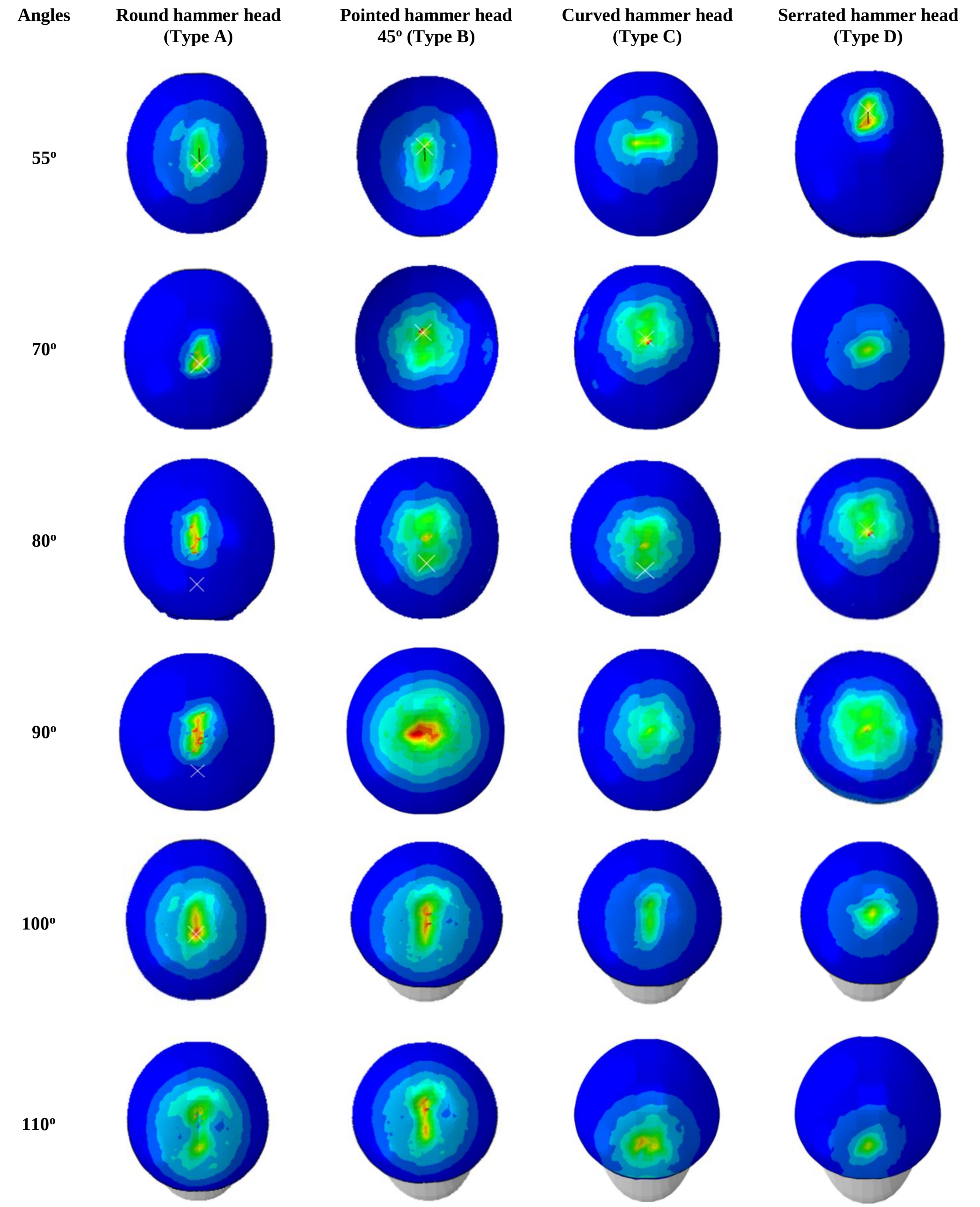


Figure 13 von Mises stress appearance at the top corner of various hammer head impacts at kinetic energy, E_k = 588 J.

Considering the damage pattern in the model shown in Figure 13, it can be seen that if one considered the impact of the hammer head falling to the center of 90° at E_k = 588 J, the point of damage of the helmet was very high. Ultimately, it was on the center of the head. As with the actual results of laboratory tests where the hammer head's impact falls on the center of the head and was compared with the model, it was found that the most likely area of damage to the material or specimen was the in the middle of the helmet, consistent with the model image, it can be seen that in the case of a non-rubber sponge, the highest von Mises stress is located in the center of the helmet. The von Mises stress angles closest to 90º were 100º and 110º. Figure 13 shows that the experiment was consistent with the model, with the hammer head providing the maximum load and the resulting von Mises stress at 45º were pointed hammer (Type B), a solid round hammer (Type A), a serrated hammer (Type C), and a curved hammer head (Type D), respectively. The von Mises stress were 15.29 MPa and 3.7 MPa. The von Mises stress was found to be at an angle of 90º - 110º, especially at 45º (Type B) hammer heads. The highest von Mises stress, 56.40 MPa, occurred at an angle of 90º, which was consistent with the experimental model with programmable considerations at E_k = 146 J, 294 J and 441 J. It was analyzed that the pointed hammer's weight characteristics were directed downwards in the pointed area and resulted in more damage than other hammerheads. Using the program to analyze the model can greatly reduce testing costs and also provide a good visibility into the tendency of material damage.

5. Conclusion

This study examined the impact modeling of helmets using four types of hammerheads: round hammerhead (Type A), 45°-pointed hammerhead (Type B), serrated hammerhead (Type C), serrated hammerhead (Type C) and curved hammerhead (Type D) with a hammer head weight of 15 kg and impact test heights of 1, 2, 3 and 4 m or at a kinetic energy, E_k = 146 J, 294 J, 441 J and 588 J. The test results at the actual impact angles in the laboratory were compared with the model results by the FEA method. The impact angles were also analyzed programmatically by FEA at 55°, 70°, 80°, 100° and 110° respectively, where test results and model analysis were approximately the same at 90º. The percentage difference between Type A, Type B, Type C and Type D hammer heads was 2.12%, 1.50%, 5.06% and 4.29%, respectively.

When a full-face helmet was considered, it was found that the impact test of the helmet using the four types of hammerheads, the 45º pointed hammerhead (Type B) dealt the most damage to the helmet. The maximum impact load from an angle of 90º at E_k = 588 J was 30.28 kN, corresponding to a model with a maximum load rating of 29.72 kN. Curved hammerhead (Type D), had the lowest speeds of all hammerheads. The influence of the impact angle given the lowest load was the angle of 55º. By programmatic analysis, it was found that an example of a Type B hammerhead at E_k = 588 J yielded the lowest load value of 22.30 kN, representing a 26.35% percentage difference from the 90º angle test where the same hammerhead would break. The angles of 100º and 110º angle had the effect of the load from the impact that was closest to the angle of 90º. In all cases, the hammer heads were consistent with the testing of several studies that analyzed the front of the helmet to be the most dangerous in the face of impact or head injury. The results of this study showed the results of the impact tests with different angle and different areas which could be contributed to design motorcycle helmets in the future. The 90º impact on the helmets seemed to gain the highest impact loads than those of the 100º and 110º impact, therefore, to help reduce impact load on the helmets, the commercial helmet designers should consider reinforce the helmets in the areas which might cause the high risk of injuries.

The advantage of using the FEA method in engineering analysis is the reduction in testing time and cost of purchasing test materials. As for the impact analysis of the helmet in various hammer head impacts, it was analyzed that the pointed 45º hammer head (Type B) was characterized by the impact of the hammer head was downward and transmitted in the pointed head area. This resulted in more damage than other hammerheads. Although model analysis by FEA methodology is convenient to use and cost-effective to experiment, in the future, further development in the field of helmet models is needed to achieve greater accuracy. Since the helmet has a curved design and complex shape dimensions, the results of the analysis may be predictable as well.

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