Component design of foldable helmet for motorcycle usage: Strength analysis under static loading

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Abstract. A helmet is used to protect the head of motorcycle rider especially when an accident happens by absorbing the impact/crash load. In Indonesia, wearing a helmet when riding a motorcycle is obligated by the constitution. Hence, in line with the quick growth of online motorbike and taxi service, carrying a personal helmet has become a common need. Yet, it becomes troublesome to carry and store the helmet due to its big size. This paper introduces a primary design idea of a foldable helmet for motorcycle rider by fulfilling the safety standard of SNI (Indonesian National Standard). The proposed helmet uses hinge components that allow the folding mechanism. Strength analysis of the hinge-pin lock system is discussed in this paper. From the result, it was confirmed that the foldable helmet could withstand a loading requirement of 3000 N at the joint system (hinge) as required by SNI. The proposed folding mechanism can reduce a helmet volume up to 50% smaller than the non-foldable one. Furthermore, this study is expected to give contribution to the engineering product design.

1. Introduction
The development of a motorcycle rider in Indonesia has increased by nearly about 20,000,000 persons in only 5 years since 2004-2005 [1]. According to Badan Standardisasi Nasional (BSN) of Indonesia, the number of motorcycle accident keep increasing from year to another [1,2]. A past study discovered that during road traffic injuries a rider without helmets were three times more likely to suffer head injuries rather than those who wear helmets [3]. Another study reported that the use of helmets could reduce the risk of head injury by 20-45% [4]. Therefore, the use of a helmet is very crucial due to the consequence of not wearing it while riding a motorcycle.

Based on the study retrieved from one-month study of all patients in Yogyakarta, Indonesia, observations show that 89% of motorcycle drivers wore helmets and only 20% of the passengers did [5]. There are various reasons for not wearing helmet, including the physical discomfort due to the shape and size of the helmet. To address this, one of the solutions is by creating a much simple helmet design which can be folded.

A foldable helmet is interesting since it offers an easy way to carry the helmet. Besides, a foldable helmet can be used not only for a vehicle rider, but also for several application, such as, it can be utilized as an emergency kit during an earthquake and for space-suit purpose [6,7]. Moreover, it may be beneficial for the innovation in science and engineering field, as well as in the field of education [8].

The present work aims to develop a foldable helmet by considering the safety standard required by the Indonesian National Standard (SNI). Considering the factor of safety and the dimensions, a strength
2. Methodology

2.1. Folding Mechanism
Figure 1 shows the proposed foldable helmet mechanism which adopt the Proteus design concept for a full-face helmet. The dimension of the full-face foldable helmet was adjusted to be the large size of SNI motorcycle helmet standard with an inner circumference of 580-620 mm [1]. The proposed folding mechanism utilizes a hinge and pin lock system.

![Figure 1](image1.png)

**Figure 1.** The Full-Face Foldable Helmet front view (a) rear view (b) side view (c) all units in mm.

The folding mechanism is adopting a hinge and pin lock system. By this mechanism, the main goal is to achieve a volume reduction of helmet of more than 40% compared with the unfolded condition. Figure 2 shows the design of the pin lock parts.

![Figure 2](image2.png)

**Figure 2.** Pinlock Interface (a) then the Pinlock Key (b) and the Pinlock Strap (c) all units in mm.

2.2. Design specification
The above folding concept is then designed to satisfy the below specifications which are determined within the boundaries defined by the SNI [1], such as:

- Foldable Helmet : Full-Face Helmet
- Strength: 300G (3000N)
- Material Selection: Non-Metal material that can withstand the temperatures of 0 - 55 °C and not affected by radiation ultra violet, resistant to effects the influence of gasoline, oil, soap, water, detergent and cleaner others
- Size: L standard with dimension diameter 580-620 mm

Moreover, the volume reduction is targeted to be more than 40%. In addition, the Design Factor, \( n_d \), is determined by considering the eight rating factors along with the rating numbers (RNs) to estimate the uncertainty of the whole design [9]. The required data is shown in Table 1.
Table 1. Rating numbers for the uncertainty parameters.

| No. | Parameters                                                                 | Rating Numbers (RN) |
|-----|-----------------------------------------------------------------------------|----------------------|
| 1   | The accuracy of the loads, forces, deflections                             | 1                    |
| 2   | The accuracy of the stresses                                               | 2                    |
| 3   | The accuracy of the failure strengths                                      | 2                    |
| 4   | The need to conserve material, weight, space, or dollars                   | 0                    |
| 5   | The seriousness of the consequences of failure                             | 3                    |
| 6   | The quality of workmanship in manufacture                                 | 0                    |
| 7   | The conditions of operation                                                | 0                    |
| 8   | The quality of inspection and maintenance                                  | 0                    |

Total Rating Numbers ($t$) 8

Where,
RN = 1 $\rightarrow$ Mild need to modify $n_d$
RN = 2 $\rightarrow$ Moderate need to modify $n_d$
RN = 3 $\rightarrow$ Strong need to modify $n_d$
RN = 4 $\rightarrow$ Extreme need to modify $n_d$

\[ n_d = 1 + \frac{(10+t)^2}{100} = 4.24 \]

Hence, the $n_d$ was found to be 4.24. Based on this value, strength analysis of the components under static loading is performed. The calculation is provided only for the most critical parts of the foldable helmet, i.e., the hinge and pin lock. Because both parts are the key of the foldable helmet mechanism, thus a detail calculation needs to be done.

3. Results and discussion

3.1. Strength analysis under static loading

The strength analysis under static loading after determining the $n_d$ was done. Free body diagram was created by applying the required 3000 N load at the edge of the hinge as shown in Figure 3 with simplified shape. The normal and shear stress were calculated in order to find the maximum stress at the component, determine the materials, and calculate the safety factors [10].

\[ \sigma = \frac{Mc}{I} = \frac{(3000 \text{ N})(2.5 \times 10^{-2} \text{ m})(1 \times 10^{-2} \text{ m})}{\left(\frac{1}{12}\right)(6 \times 10^{-2} \text{ m})(2 \times 10^{-2} \text{ m})^3} = 18.75 \text{ MPa} \]

Figure 3. Free-body diagram of the hinge component.
\[ \tau = \frac{3V}{2A} = \frac{3(3000 \text{ N})}{2(6 \times 10^{-2} \text{ m})(2 \times 10^{-2} \text{ m})} = 3.75 \text{ MPa} \]

Using the calculated stress values, we can determine the minimum yield strength to select the suitable material. Here, the normal stress due to bending moment is chosen because of its bigger value.

\[ S_{y-min} = n_d \times \sigma_{Max} = 4.24 \times 18.75 \text{ MPa} = 79.5 \text{ MPa} \]

Based on the list of material shown below, the material selection has been limited into not choosing any kinds of steel but preferable polymers with yield strength above 79.5 MPa such as [10]:

1. Nylon 6/10 = 139.043 MPa
2. ABS = 55 MPa
3. Nylon 101 = 60 MPa
4. PA Type 6 = 103.65 MPa

Therefore, based on the strength considerations, PA Type 6 has been chosen as the material for the hinge. Nylon 6/10 was not chosen due to different weight comparison of Nylon 6/10 and PA type 6. It has been checked that the PA type 6 is more lightweight compared to Nylon 6/10 with density 1120 kg/m\(^3\) for PA type 6 and 1400 kg/m\(^3\) for Nylon 6/10. Using this material properties, the safety factor \((n)\) can be calculated as

\[ n = \frac{S_y}{\sigma_{Max}} = \frac{103.65 \text{ MPa}}{79.5 \text{ MPa}} = 5.75 \]

As for the second most important part, the applied force of 3000 N will be distributed uniformly through each number of pinlock teeth. There are approximately 5 pinlock teeth in the pinlock strap as shown in Figure 4. Thus, the applied force on a single pinlock teeth will be calculated as 600 N, thus it should hold a moment load of 0.6 Nm.

\[ \text{Figure 4. Free-Body diagram of a single pinlock teeth.} \]

Then, the stress worked on a single Pinlock Teeth can be calculated,

\[ \sigma = \frac{Mc}{I} = \frac{(0.6 \text{ Nm})\left(\frac{1}{3} \times 1 \times 10^{-3} \text{ m}\right)}{3.123 \times 10^{-11} \text{ m}^4} = 0.63 \text{ MPa} \]

Based on the value, the minimum yield strength value required to determine the Pinlock Teeth Material is calculated.

\[ S_{y-min} = n_d \times \sigma = 4.24 \times 0.63 \text{ MPa} = 2.7 \text{ MPa} \]

Based on the obtained value, the same material for making the pinlock PA Type 6 is chosen. The same material is chosen to simplify the manufacturing process. In addition, the safety factor, \(n\), for the pinlock teeth is calculated, resulting in a big value.

\[ n = \frac{S_{y, PA}}{\sigma_{Max}} = \frac{103.65 \text{ MPa}}{0.63 \text{ MPa}} = 163.59 \]

As the future works, strength analysis using finite element method to understand the dynamics behavior and vibration mode under impact loading from different directions will be conducted. This is to
comprehensively understand the failure mode of the proposed helmet under static and dynamics [11, 12].

3.2. Volume reduction
Below is the calculation of volume reduction of the proposed foldable helmet.

\[
\text{Volume Unfolded (Vu)} = \frac{4}{3} \times \pi \times 350 \text{ mm} \times 300 \text{ mm} \times 250 \text{ mm} = 109955742.9 \text{ mm}^3
\]

\[
\text{Volume Folded (Vf)} = \frac{4}{3} \times \pi \times 350 \text{ mm} \times 250 \text{ mm} \times 150 \text{ mm} = 54977871.4 \text{ mm}^3
\]

\[
\text{Volume Reduction} = \frac{\text{Vu} - \text{Vf}}{\text{Vu}} \times 100\% = \frac{(109955742.9 - 54977871.4) \text{ mm}^3}{109955742.9 \text{ mm}^3} \times 100\% = 0.5\%
\]

Based on the calculation above, volume reduction was found to be 50%. This value satisfies the initial goal which was targeted to be 40% volume reduction. Current volume reduction can be considered the highest possible because the helmet also contains the foam material for impact-absorbing part [13].

4. Conclusion
The design concept and strength analysis under static loading of a foldable helmet model adopting the Proteus folding mechanism have been introduced. The results show that proposed foldable helmet can offer a 50% volume reduction under folded condition, and can withstand the loading requirement of SNI of 3000 N at the joint system (hinge-pin lock system). In other words, when a motorcycle rider gets an accident, the head injury due to failure of the joint system could be avoided. Further improvement still needs to be done as future works such as numerical computation, dynamics behavior investigation, and the fabrication process.

Acknowledgements
Authors wishing to acknowledge and express gratitude to Faculty of Engineering and Technology of Sampoerna University, for facilitating this research.

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