A CONCEPTUAL DESIGN OF SECONDARY PADDING OF CHILD HELMET USING SWIMMING TUBE

S. Akmal[1], M.H.F.M. Fauadi[1], R.H. Hambali[1], N. Hadzlin[2] and R.S. Taufik[3]

[1]Fakulti Kejuruteraan Pembuatan,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]Galvano Technology,
Taman Riang Ria, 81200 Tampoi
Johor, Malaysia.

[3]Binus Graduate Program,
BINUS University, Jl. K. H. Syahdan No. 9, Kemanggisan, Palmerah, Jakarta 11480 Indonesia.

Corresponding Author's Email: [1]suriatiakmal@utem.edu.my

Article History: Received 17 January 2018; Revised 16 June 2018; Accepted 14 October 2018

ABSTRACT: Due to unavailability of a helmet that is below 57 cm in diameter, this paper presents the design of a child's helmet that has the flexibility to suit any head diameter size of children in Malaysia. The target group of this proposed helmet is children from 2-6 years old. The scoring concept was used to select the proposed design. It reuses the conventional kid helmet structure in the market by making sure the re-processing of broken swimming tubing material. The unique characteristic that tube has is the ability to inflate and in this paper, is called as secondary padding that located in the inner shell of a proposed helmet. A finite element analysis using SolidWorks software was conducted for evaluating the static analysis of secondary padding which includes stress, displacement, and strain. The results show that the secondary padding using swimming tube design is safe to use with the condition of 8.357e6 N/m^2 maximum von Mises stress with a safety factor of 1.523.

KEYWORDS: *Child Helmet; Swimming Tube; Inflatable Tube; Conceptual Design; Child Pillion Rider*

1.0 INTRODUCTION

The road traffic accident is the main cause of death in Malaysia with almost 62% of the road accidents involved motorcyclist [1]. In Malaysia, the motorcycle is the major mode of transportation especially in the rural area and has brought more than 60% fatalities which are higher than cities area [2-4]. The number is increasing in average rate of 5% year by year [5]. In the literature section, it is mentioned that there are a lot of factors that cause accidents to happen for example the lost in balance, the small dimension of tire and motorcycle's body, the road surface, and limitation of protection to the motorcyclist [2, 4].

In Malaysia, the law of wearing a helmet was introduced since 1980 [6]. The helmet is the smallest physical protection that is available to protect the cranium of a motorcyclist and pillion riders. Generally, there are four types of helmet available in the Malaysian market: (1) the half-head; (2) the tropical helmet; (3) the open-face and (4) full-face. The standard of the helmet in Malaysia is monitored by the Standards and Industrial Research Institute of Malaysia (SIRIM) which is based on R22 UN Regulation for protective helmet [7]. Despite many laws and interventions introduced to protect the motorcyclist, the number of crashes and fatalities are increasing yearly [7-8]. According to World Health Organization (WHO), the major cause of death is the head injury [9]. It is reported that in 2010, in a survey done in Selangor, Malaysia, out of 1150 motorcyclist only 46.6% used helmets properly, 10.6% untied helmet and 42.8% ride their motorcycle without-helmet [10]. In addition, 81% of the respondents have the full shell type of helmet design, 15% uses a full face helmet and only 4% possess half-shell helmets.

The number of causalities involving children in the country is a significant concern. In Malaysia, the pillion riders especially child encompasses 19-20% fatalities [4]. Another study by Mohamed et al. [11] showed that children in Malaysia are exposed to the risk of road crashes. Around the world, children as pillion riders are exposed to motorcycle injuries. For example, according to a report by FiA Foundation [12], children between 0-17 years old who died in motorcycle accidents in Uruguay increased by 67% in 2016 compared to the previous year. The number accounts for more than half of the total number of deaths involving motorcycle in Uruguay.

Another report by WHO states that almost 95.7% in India and 96.4% (Thailand) children involve in motorcycle injuries as they did not

wear a helmet and this leads to brain injury (37.2%)[13]. Most of the mentioned countries including Malaysia categorized as low and low-middle income countries in which motorcycle is the main mode of transportation. Causes of accidents in the low and low-middle income countries are due to unsafe driving behavior, neglecting the helmet legislation and appropriate or standard helmets are not used [14-15].

Recently, the topic of child motorcycle pillion rider, the use of a helmet by child pillion riders, suitability of children traveling on a motorcycle [16] and the impact of legislating usage of helmet towards children such as in Vietnam [17] were studied. According to Pervin et al. [17], most of the countries in the world has imposed the legislation on helmet wearing requirement. Most countries including Malaysia do not set the standard of age limit for the child pillion rider and no requirement on feet distance that must reach the foot-rest. Moreover, there is only one standard for motorcycle safety helmet that is applicable for both adult and children-sized helmet in Malaysia [4, 16]. Only Vietnam has the standard for child's helmet in the form of technical regulation [18]. In Malaysia, the type of standard-compliance of children helmet is full face helmet, on the other hand, Vietnam allows the half helmet [16].

Likewise, Hamzah et al. [4] and Faradila et al. [16] state that the available minimum size helmet in the market is 57 cm in diameter to cater various children age groups. The adult anthropometry has been used to design a child's helmet. The size is not satisfactorily suitable for the size of the head of children who are younger than seven years old and this is putting them in danger of serious head injury if they were involved in road crashes.

Due to limitations on the availability of the Malaysian children helmet size and children anthropometry data, this paper focuses on modification of the internal structure of existing standard-compliance children helmet in Malaysia. Also, the authors' have a limitation on the impact testing equipment. Therefore, this study reuses the existing helmet for children that have the certified SIRIM. For this purpose, the helmet is designed in such a way that the inside shell is equipped with a secondary padding that suits for almost all sizes of children's head.

2.0 RELATED WORK

2.1 The customer requirements

Fulfilling the customers' requirements has been recognized as an important factor in order for product development to succeed [19]. A product that is able to satisfy and delight the customer requirements will depend on the product's attributes [20]. According to Mkpojiogu and Hashim [21], in product development, it is necessary to give adequate attention to customer's requirements from elicitation of product attribute to design and to the final stage of the design process that significantly supporting the design team producing the desired value to the customer.

There are many ways to collect customer requirements such as interviews, focus group, observing the available product in use, and questionnaire [22]. The interview is a technique which conducted in the customer's environment. The design team should be well understood the problem and prepared before the interview process. The design team can ask the open-ended question as well as closed-ended questions. The open-ended questions require the interviewee to explain their thoughts and closed-ended questions refer to a more specific answer. Another direct approach in collecting customer's requirements is questionnaires. It allows the design team to collect high-quality information from many people which are spread out geographically. Questions in the questionnaires are always about the environmental use of the product and its features.

2.2 Children Helmet

To better understand the suitable helmet for child pillion riders, several existing helmets were studied. Some of the child helmets are listed in Table 1. As mentioned previously, only Vietnam has the technical standard for children's helmet as shown in Table 2. Differences in terms of design between the standard helmet for Malaysia and Vietnam are presented in Figure 1. Figure 2 shows a helmet consists of four basic components which are required to provide protection for motorcyclist: an outer shell; an impact-absorbing liner; the comfort padding; and a good retention system.

The outer shell is usually made from fiber-reinforced composites or thermoplastics like polycarbonate. For the inside part of the shell, the material is made of expanded polystyrene (commonly known as Styrofoam). This dense layer cushions and absorbs shock as the

helmet stops but still the head keeps on moving. In addition, both shell and the liner will compress if it is being hit so hard, spreading the forces of impact throughout the helmet's material. Due to several limitations of the authors' environment such as impact testing equipment and the available data on children anthropometry, this paper focuses on the comfort/fit padding.

Table 1: Comparison of child helmet standard for several countries [4]

Standard	Snell-FIA CM2007 Standard for Protective Headgear	MS1727 : 2004 Impact protection helmets for young children	MS1:1996 Spec for Protective Helmet for Road User	Malaysia Patent PI 20031295 Safety Helmet for Children	ECE R22 Standard for Helmet and Visors	Vietnam Technical Regulation for Protective Helmets QCVN 2:2008
Scope	Children motorsports use	Motor vehicle Free environment , < 7 years old	Vehicle user	Children	Moped and motorcycle use	Road users and moped
Size, cm	<49–59	50–62 Headform	50–62 Headform	45–60	50–62 Headform	<50, 50–52, >52
Mass, g	1 000–1 300	No requirement	No requirement	500–1 000	No requirement	Full face, *L <1 500, M&S <1 200, Open and ½ Shell, L <1 000 M&S <800

Note: * L means Large: > 52 cm circumference, M medium: 50 to 52 cm circumference, S small: <52 cm circumference.

Table 2: Availability and sizes of children helmets in Vietnam [18]

Brand	Size	Head size (cm)	Age relevance of head size		Helmet weight (kg)
			Boys	Girls	
PROTEC	XS	48-51	22-60	30 - >60	0.23
PROTEC	S	50-52	59- >60	59- >60	0.34
AMORO	S		59- >60	59- >60	
ANDES	S	50-53	59- >60	59- >60	0.4
OSAKAR	S	50-53	59- >60	59- >60	
PROTEC	M	53-55	>60	>60	0.36
OSAKAR	M	54-56	>60	>60	
ANDES	M	54-56	>60	>60	0.55
EVO	M	56.5-58.5	>60	>60	0.4
EPIC	M	56.5-59.5	>60	>60	0.45

(a) (b)

Figure 1: An example of standard-compliant helmets for children (a) in Malaysia [16] and (b) in Vietnam [23]

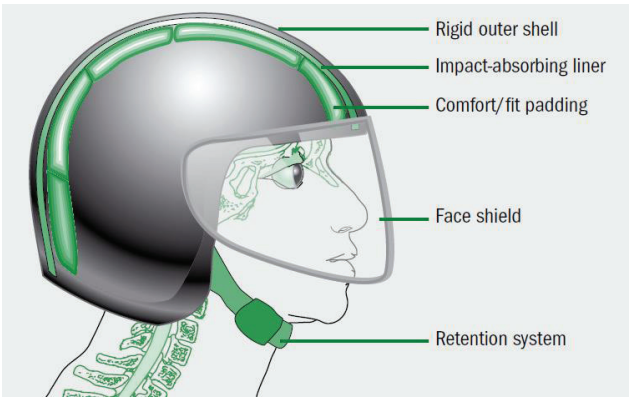


Figure 2: The screen dump of the element of a cross-sectional area of a motorcycle helmet [24]

3.0 RESULTS AND DISCUSSION

3.1 Identification of conceptual design

The study was conducted as a fulfillment of the requirement of manufacturing engineering capstone design class at a government Higher Learning Institution. The course is in the third year of the degree program. Thus, they are considered as a novice designer and the study is considered as a preliminary study. To elicit the customer requirement, a Likert scale based questionnaires were used. The preliminary study was conducted at a government Higher Learning Institution in Melaka. Based on the observation parents who use a motorcycle to transport their children is limited to 15 persons and the age of their children is in between 3 to 6 years old.

This is in parallel with Hamzah el at. [4] stated that the current children that are compliant to Malaysian standard MS 1727 require a minimum size of 50 cm which may not satisfactorily correlate to the head size of children younger than seven years old. A survey was distributed to 15 respondents and they were required to rate 6 defined attributes of the helmet. The design attributes were identified from journals and reports. One of the important attribute is safety. It is reported that safety is important in reducing the harmful impact to the head of the children [25-26]. Table 3 shows that almost 36% of respondent agreed that cost is the most important attribute in purchasing/possessing a helmet. This is followed by attributes of safety and comfort.

Table 3: Requirements for child helmet

Requirements	5 = Very Strong	4 = Strong	3 = Neutral	2 = Weak	1 = Very Weak
Cost	36%	36%	18%	9%	-
Weight	-	55%	36%	9%	-
Safety	18%	45%	36%	9%	-
Reliable	-	54%	36%	9%	-
Comfortable	9%	18%	27%	45%	-
Aesthetically pleasing	-	-	27%	45%	27%

After analyzing the customer's requirement, brainstorming is used to generate product's specification. Several factors are required to be taken into considerations when designing the child pillion rider helmet such as the suitable material, the comforting element needed to be applied in the design, and the shape of the helmet which consists of the aesthetical element.

For further steps, four important parts emerged from the analysis of existing helmet was analyzed. This study focuses on the third layer (secondary padding) and adjustable parts of the helmet. This is because the existing helmet has a structure which is compliance with the Malaysian standard except for the inner part that is suitable for 7 years old rider. The function of secondary padding of the helmet is to fix different head size and to provide comfort. There are three workable solutions for secondary padding: (1) foam; (2) leather; (3) combination of foam, small bead polystyrenes, and fabric. Solution 1 and 2 has the limitation in which the terms of fix size of head and leather is not cost-wise to be the inner part of the helmet for mass production. Due to this reason, solution 3 was chosen as the best solution. There are five design alternatives that have been proposed for secondary padding of child pillion rider helmet (Figure 3). All

concepts should propose a part that can be compressed and deflated easily. The team decided to make use of the practice of reuse concept.

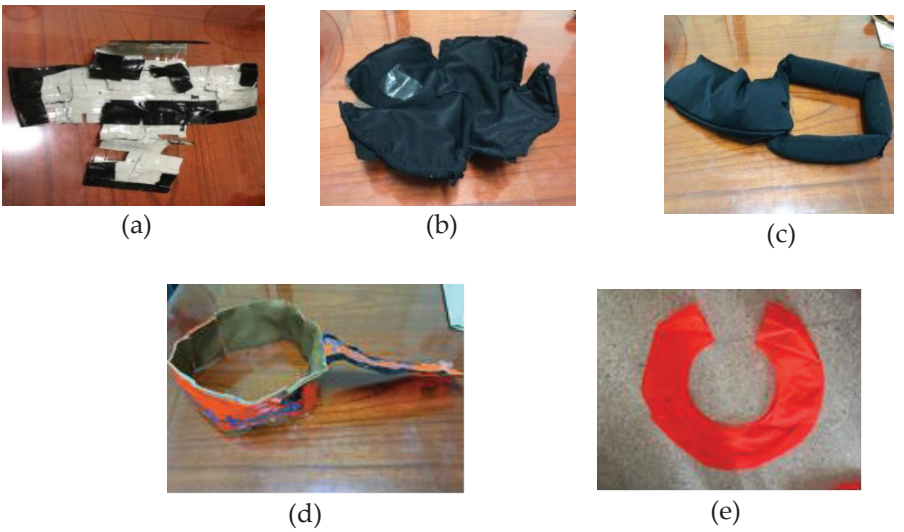


Figure 3: The initial design concepts for secondary padding: (a) concept 1, (b) concept 2, (c) concept 3, (d) concept 4 and (e) concept 5

All design concepts are focusing on providing comfort to the user and reduces the gap between the child's head and inner shell of the helmet. The concept design 1 is made of PET plastic and designed in T-shape. The design has a thin layer of the materials which failed to meet the standard engineering requirements such as stiffness, fracture toughness, and comfort. The concept designs 2 and 3 use expanded polystyrene. They are different in shape in which concept design 2 imitates the petal design and concept design 3 is a tie-shape. The round pattern in concept design 3 cover the head circumference of the child and the longer part is to protect the upper part of the head. Similar to concept design 3, concept design 4 proposed material from the swimming pool to be the secondary padding. For this purpose, the existing design was modified into a round shape which is similar to the head circumference. However, the user will face difficulties in blowing the air into the tube. Concept design 5 is based on concept design 4. They are different in terms of processing method to seal the proposed material.

Scoring concepts were employed in order to minimize the selection of proposed concepts. The selection criteria are developed based on customer's requirements. In this study, the reference concept refers to

the existing helmet in the market. All concepts were analyzed with a group of experts. Concept designs 3-5 provide comfort, however, concept designs 3 and 4 failed to meet the basic purpose of the proposed design which is the adjustable effect that can provide any sizes of head circumference of a child. Based on scoring method Concept 5 was selected and proposed the use of the inflatable tube as secondary padding for the child helmet to overcome the current limitation. The proposed concept imitates the function of a lifebuoy. In this study, the function of the inflatable tube is to fix all sizes of children from 2 to 6 years old and it offers comfort to the user. The secondary padding is still in the initial design process, therefore, a further study which uses another design approach as stated in [27-28] is required in order to improve the design process and give benefits to society.

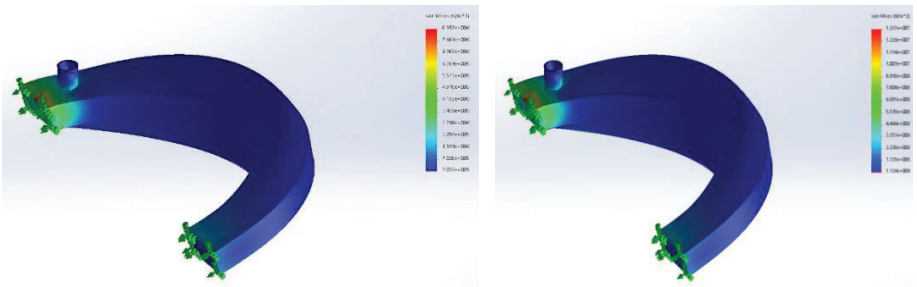
3.2 Simulation of conceptual design

The SolidWorks Simulation Xpress that uses finite element code was carried out to study the behavior of secondary padding and to investigate its performance and safety. In regard to SolidWorks Simulation, material properties are absolutely necessary for the calculations of stress and displacement. Under these circumstances, the material properties of Polyvinyl chloride (PVC) 0.007 plasticized as shown in Table 4 were available under the plastic options inside of the SolidWorks material library. The analysis focuses on linear stress analysis that includes maximum von Mises stress and deformation. The number of mesh applied to the structure is 3.557 mm.

Table 4: Material properties of PVC 0.007 plasticized

Property	Value
Elastic Modulus / Young Modulus	6.0e6 N/m^2
Poisson's Ratio	0.47
Tensile strength	(1.4e3 MPa)
Mass Density	1.290 mg/mm^3

The pressures applied for this analysis are 5 MPa, 10 MPa, and 16 MPa. Figure 5 and Table 5 show the results of the analysis. In all conditions, the maximum von Mises stress occurs at the end of the secondary padding which is near to the pressure inlet. To ensure the design of secondary padding is safe to use, a factor of safety was calculated and a value greater than 1 is acceptable. It is clear from Table 5 that the factor of safety for all pressure is greater than 1.0. The secondary padding fails when a pressure of 16 MPa was applied.



(a) (b)

Figure 5: Results of maximum von-misses stress for the pressure applied at: (a) 10 MPa and (b) 16 MPa

Table 5: The resulting analysis

Pressure Applied (MPa)	Maximum Von-Misses Stress (MPa)	Maximum Deformation (mm)	Safety Factor
5	4.178e2	3.387e1	5.505
10	8.357e2	6.744e1	1.523
16	13.37e2	10.84e1	0.972

4.0 CONCLUSION

A secondary padding is proposed in this paper to overcome the limitation of existing child helmet. The secondary padding has an inflatable characteristic is suggested to make use the recycle swimming float as the main body. The main function of this secondary padding is to fix the child head in the inner structure of the helmet without producing any air gap between them and provide comfortability to the user. The simulation results show that the secondary padding can withstand up to pressure of 10 MPa with maximum von misses stress of 8.357e6 N/m^2 and a safety factor of 1.523. For future works, the study can be extended by collecting more data from all kindergarten in Melaka. Also, a new material of the proposed secondary padding could be further studied.

ACKNOWLEDGMENTS

The authors are grateful to all those who have assisted direct or indirectly to complete this study at the Universiti Teknikal Malaysia Melaka. The authors would like to thank the Fakulti Kejuruteraan Pembuatan for supporting this study.

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