DESIGN AND ANALYSIS OF BICYCLE HELMET MOULDING PROCESS DEVELOPMENT

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Abstract. The use of material like synthetic plastic going through injection moulding arising the health problem and hazard to the operator and the environment. The melting plastic used for injection moulding are hazardous to the operator where the potentials of getting skin burns from contact with the heated barrel or from splattering hot plastic and gases or vapours. Photochemical oxidation contain in the plastic depleting the ozone layer. The aim of the study is to design an open mould suitable for the hand lay-up technique of the Kenaf fiber with epoxy resin adhesion. The analysis of the mould designed by using CAD is to study its mechanical properties such as plasticity. The analysis shown the critical part of the moulding is at its centre where the deformation happened. The mould will return to its original shape when the force applied is removed due to the maximum value for shear and equivalent elastic strain did not reach 0.4 m/m which will cause silicon rubber material to tear and failed.

Keywords: Open Moulding, Hand Lay-Up, Epoxy And Kenaf Fiber Reinforcement.

1 INTRODUCTION

The research draws attention to the fact that conventional mould making that is by using injection moulding and thermoforming is hazardous to the environment and the operator and also to the fact that accident involving head injury among cyclist is about 3578 in average anually due to lack of knowledge on the safety and material quality of the helmet worn [1]. The concern of the non-biodegradable material also is one of the major contributors to environmental hazard [2] as most of the bicycle helmet available in market today is made out of synthetic material. Improvement on the material suggested that the outermost shell of the helmet be upgraded with fiber reinforced epoxy. Open moulding is the most suitable for fabrication of epoxy resin with kenaf fibre reinforced product as the hand lay-up technique can be used in the outer shell of bicycle helmet development.

Advance technique for analyzing a design such as rapid prototyping enable the realization of the product design and allow detection of flaws at early stage [3]. Fused Deposition Modelling (FDM) is one of technology in rapid prototyping technique that used acrylonitrile Butadiene Styrene (ABS), polyamide, polycarbonate, polyethylene, polypropylene as basic material. Besides, silicon nitrate, aluminium oxide,
hydroxypatite and stainless steel also can be used for special application of FDM [4]. Product design in CAD file must be converted to a format that a 3D printer can understand. The file will be converted into STL format in order for the process of rapid prototyping of the mould of the outermost shell of the bicycle helmet to be proceeded. Using this technique, the elimination of ‘trapped volume’ problems, producing sacrificial wax pattern do not require the expensive conventional tooling good surface finish, complex geometries possible and good general accuracy [5]. Mould making using liquid silicone rubber (LSR) has the quality stated which gives benefits to manufacturer to produce their desired product. It is and excellent choice for the use of indirect tooling of rapid tooling technology where the cost of development process of the new product can be reduce, easier to work with, reducing time of manufacturing and it is flexible and has elastic characteristics which allows the fabrication of parts that have complex geometry which is suitable for the production of composites make it easier for the outer shell of bicycle helmet to be dismantle from the mould[6].

The significant consideration of producing the mould out of the LSR is the thickness of the wall thickness of the product [7]. Research by A. Pervin [2] shows that hand lay-up technique is a technique that can accommodate with the production of a composites product. The advantages of implementing the technique when tempering with composite are the hand lay-up method can be used to make very large and complex parts. Based on Davoodi, M.M [8] study, natural fiber offers advantages over synthethic fiber which are better formability, renewability, abundant, cost effective, acoustic properties and most important is that it is safer towards health. Kenaf have been familiarize as the vital source of fiber for composites and other industrial uses according to [9]. One of the advantage of kenaf fiber is the non-appearance of silica content which is important in reducing the abbrassivenes to the processing equipment [10]. Therefore, the fiber out of kenaf plant is suitable for several application as reinforcement in polymer composites, insulation board, and as absorbant material which the outershell of the bicycle helmet crucial role [11].

2.0 METHODOLOGY

2.1 Material Selection

Liquid silicone rubber is a material that has the versatility in manufacturing industry with available hardness from 10 to 80 shores with consistency in product dimensions, precisions and lighter in weight than conventional steel made moulding [11] thus, making it suitable for the production of the outermost shell of the helmet’s moulding. Its properties are very suitable to be used as the moulding material and it is compatible to be used with epoxy which is the material selected for the helmet outer shell. Kenaf fiber is chosen as the reinforcement which will enhance the mechanical properties of the outermost shell of the helmet also have the advantages over the synthetic fiber [12].

2.2 Mould Designing and Analysis Method

Mould designing start with analysing the suitability of which type of moulding can be applied for hand lay-up technique. Then, the design part is analysed using ANSYS Software to study on the plasticity if the mould. Before developing design, A few criteria need to be considered for the mould. The criteria needed or called product design specification (PDS) are listed in Table 1. Four design sketches are produced and drawn by using Solidwork® software based on the PDS table. Then, Pugh Concept Selection method is used to determine the best conceptual design among the four design concepts selected.

| Criterion | Specification |
|-----------|---------------|
| Performance | Mould must have high frequency of reuse ability as it will be |
| Used for many times. | Safety | Mould material must be environmental safety. Mould design should have minimum sharp edges as it can be dangerous during lay fabrication process |
|---------------------|--------|------------------------------------------------------------------------------------------------------|
| Strong mould body.  | Manufacture-ability | Material used for mould must be easy to manufacture and fabricate. Mould design must be easy to fabricate and manufacture. Type of mould (open mould, injection) must be easy to performed and suitable with the helmet design. |
| Highly durable and ductile | Weight | Mould material should be light weight in order to ease the fabrication process |
| Material | Easy to get and low cost Mould material must be suitable with the material will be used for the helmet product |
| Cost | Low cost of manufacturability design, Low cost material |

2.3 ANSYS Software Analysis Method

After finish with the mould design process, stress analysis was applied to the design drawing. ANSYS software allows user to do stress analysis by applying material selected by users. From the analysis, high stress area and low stress area can be seen. High stress area will be in red colour while low stress area will become blue. From the analysis, failure of the design can be identified. If the product failed, new product design needs to be developed.
2.4 Mould Fabrication
The fabrication of the mould start with 3D printing of the bicycle helmet shell using filament type of 3D printer. The design is divided into four as shown in Figure 2 so that it is compatible with the allowable dimension for the 3D printer which is 300 x 300 x 400 mm.

2.5 Liquid Silicone Rubber Moulding Process
Liquid silicone rubber moulding process starts with weighing the silicone rubber resin with the lab weighing scale. The ratio for curing agent to be mixed with the resin as suggested by the manufacturer in 100: 1.5 by mass. The hardener is poured into the resin so that it will retain the shape of the bicycle helmet’s shell. Using the pneumatic mixer, both of the resin and the hardener materials are mixed until it is well blend. The mixture undergoes degassing process for 10 minutes in the vacuum casting machine so that air bubble can be eliminated to avoid defects on the finish product. After the degassing process complete, the mixture is poured onto the 3D printed helmet shell prototype.

2.6 Bicycle Helmet Outer Shell Fabrication
The fabrication of the bicycle helmet is proceed by applying wax thoroughly the surface making sure that the surface has all been fully covered. This process has to be taken seriously because if the applied wax is insufficient, it will affect the result especially on the bend side of the ear cover of the helmet outer shell where defect will occur. Insufficient wax also will leads to the inconvenience in dismantling the helmet shell from its mould. Thin plastic sheets are used at the bottom of the mould surface to obtain good surface finish of the helmet shell. Applying the hand lay-up technique of moulding is proceed with the application of reinforcement in the form of chopped strand hairs are cut according to the mould size and placed at the surface of mould after perspex sheet. Kenaf fibre is laid on the surface of the mould, the mixture of epoxy resin and hardener is rolled against the laid fiber. To complete the process, the epoxy is left to be cured. The laying process is repeated until the desired shape of the helmet shell is produced.

3.0 RESULT AND DISCUSSION
3.1 Ansys mould analysis
From the analysis, a few data was recorded. The first data taken is shear and normal stress. Shear stress occurred when perpendicular force applied to the mould surface. The purpose of shear analysis is to define
the shear strength of the mould. With maximum shear stress 3.11MPa recorded from the analysis, the mould can be considered as safe and does not fail or tear. The region affected is shown in Figure 3.

![Figure 3. (a) Normal Stress Region, (b) Shear Stress Region](image)

3.2 Total Deformation
The deformation analysis recorded a slight deformation occur at the mould when force was applied. 0.00022755m is the maximum value of maximum deformation recorded from the analysis. Next analysis is strain analysis. The maximum value of shear elastic strain occurred at the specimen is 0.00222 m/m. Meanwhile for equivalent elastic strain the side area of the specimen experiences 2.20x10⁻⁵ m/m and the maximum elastic strain occur at the specimen was 0.002898 m/m. Region affected is shown in Figure 4. This analysis shows the affected area should be carefully handle while rolling the epoxy and Kenaf fiber onto the surface with red mark as the deformation tendency is very high.

![Figure 4. Total Deformation](image)

3.3 Total Elastic Strain
Elastic strain can be defined as form of strain in which the distorted body return to its original shape. Shear strain is a force parallel to the face of an element. Thus, from the analysis, it can be stated that the mould will return to its original shape when the force applied. This is because the maximum value for shear and equivalent elastic strain did not reach 0.4 m/m which will cause silicon rubber material to tear and fail. The analysis is necessary to highlight the ability for the mould to retain its shape after the process of dismantling the outer shell off the mould. The mould is reliable in terms of elasticity as the most critical part is only marked coloured yellow which is intermediate stress area.
3.4 Mould Fabrication using Rapid Prototyping

The sections divided is being validated in the 3D printer built-in software to observe if there is any unfitted part that will not be printed.

![Figure 5. Total elastic strain](image)

![Figure 6: Printed Divided Sections](image)

The sections of the helmet that have been printed completely and the support is detached from the product and sand paper was used to remove any bur or support chips left and then the four parts were assembled by using “507 glue” that is specified for plastics joining.

3.5 Mould Making Using Liquid Silicone Rubber

Mixing ratio suggested for the silicone rubber and hardener is 100g silicone rubber resin and 1.5 to 2.5 gram of curing agent. However, manufacturer states that every package of 5.2 kg silicone rubber resin delivered is given with 0.2 kg curing agent. By checking the weight ratio using the weighing scale, the resin and hardener is mixed with the pneumatic mixer until it blends well. Unfortunately, the mixture hardened before the mould can be fabricates. The crystallization of the liquid silicone rubber may be catalysed due to improper storage, temperature during delivery or the material is stored more than 12 months in inventory thus influencing the time for the liquid silicone rubber to cure because long-term of stockpiling may results in increasing of its Mooney viscosity (Wacker, 2014). To counteract the problem with limited material left, the liquid silicon rubber is laid on the 3D printed helmet prototype repeatedly with minimum calculated ratio which is 200:6 by mass. The mixture is being laid up on the 3D printed helmet prototype repeatedly until desired thickness is obtained.

3.6 Mould Making Using Liquid Silicone Rubber

The process of developing the outermost shell of the bicycle helmet is by using hand lay-up technique. The material used is epoxy resin, hardener and Kenaf fibre as the reinforcement. The process starts with layering up the first layer that is the epoxy resin and hardener mixture with mixing ratio of 5:1 followed by layering up with Kenaf fibre and back with epoxy resin fibre to complete the hand lay-up process. The results obtain shows that the mixture of epoxy resin and hardener takes 2 days to set with the Kenaf fiber reinforced.
4.0 CONCLUSION AND RECOMMENDATION

In conclusion, liquid silicone rubber is suitable to be used as moulding material due to its versatility and manufacturability according to the analysis defined by ANSYS where mechanical properties of this material is relatively high. The results from the ANSYS analysis of bicycle helmet mould from liquid silicone rubber material is suitable to be used in fabricating product from epoxy resin with Kenaf fibre reinforced.

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Figure 7. Epoxy with Kenaf reinforced Outer Shell of Bicycle Helmet
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