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Procedia CIRP 37 (2015) 95 – 100

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CIRPe 2015 - Understanding the life cycle implications of manufacturing

# Conceptual mold design for multi-curved natural fiber reinforced composite body armor panel

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**Abstract**

The development of lightweight and inexpensive body armor products is under on-going attention by both manufacturers and users. In general most body armor panels are made either from ceramic or composite materials using various manufacturing techniques such as manual layup, compression moulding, *etc*. However, for natural based reinforced composite which the reinforcement material is in powder or particulate form, such technique have to be specifically modified to achieve workability in the actual fabrication process. This paper present a systematic design approach on fabricating a natural based particulate composite mold using compression molding method. A Total Design Method was utilized in generating the concepts of multi-curved body armor molds with different ejection system. The significant criteria in the mold concept design selection were found to be the fabrication process, maintenance and cost. Further analysis such as machining time and fatigue life estimation were done to evaluate the workability of the selected concept design.



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*Keywords: Compression mold; natural fiber; total design method, curvature*

## 1. Introduction

Mankind used various types of material and design as armor to protect themselves from injury in any threatening situations recorded in history. The early defensive garments and shields were produced using creature skins, wooden and metal shields. Since 1500s and till now, metal based body armor had steadily improved with the manufacturing technology [1–4].

Typically, rigid body armor is fabricated in concave or flat shape configuration to enhance ballistic protection and suit the wearer's anthropometry. The body armor protects the wearer from ballistic threat that normally target the critical organs located at the chest and back region. The armor material panel may consist of ceramic face with a fiber reinforced backing as spall liner or a monolithic type of metal sheet. The design can be varied in terms of material types, panel thickness, spall liner thickness, and resins used to bond the materials together. [5–7]

One of the common manufacturing method to produce rigid body armor is by using compression molding due to its cost-effectiveness and efficiency. Compression molding can mass-produced products for ceramic and composite type of armor at higher compaction loading, leaving less void in the product or energy wastage. However, there are certain challenges in fabricating rigid body armor made from composite material mostly due to its quick setting resin issue and reinforcing material options are limited to chopped fiber or localized reinforcing with low flow type of material. This make compression molding harder for composite armor designer who are interested to venture into "greener" composite which utilized natural based reinforcement materials such as kenaf,


Peer-review under responsibility of the organizing committee of CIRPe 2015 - Understanding the life cycle implications of manufacturing
doi:10.1016/j.procir.2015.08.017

coconut, sisal, hemp,etc. These fibers offer certain advantages; nonabrasive to processing equipment, biodegradable and possees high specific strength to weight ratio.

There is a reported study which used coconut shell powder reinforced composite with spall liner can provide ballistic resistance up to NIJ 0101-08 Level IIIA [13]. The coconut powder composite was fabricated into small tiles using compression molding and were then arranged into a larger panel as shown in Fig.1

Fig.1. Coconut powder composite small tile configuration.

The aim of this paper is to virtually design a conceptual multi curved rigid body armor mold which can omit the flaw from previous process of small tile arrangement (fabrication and assembly time) and produce a monolithic panel in a single process. The mold design in this study will be developed for fabrication using a hydraulic cold press machine.

## 2. Total Design Method

The total design method (see Fig.2), a generally known concept design system which identify the procedures, aspects that can influence the quantity or quality and design in order to achieve the need of consumer or industry [8-12]. This process normally is initiated with the product evaluation process, or PEP. The total design method usually formulate a center core of activities which each activities are important for the proposed design. The activities are comprise of conceptual design, product design specification, detail design and fabrication. For this study, the fabrication is not reported in this paper but will be substituted with a simple finite element analysis. All proposed design begin with outlines a specific need in order to comply with the requirement in typical body armor manufacturing industry.

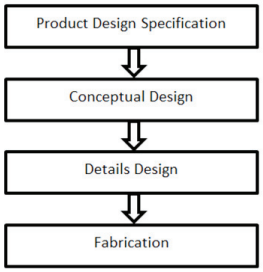


Fig. 2. Design Core Activities (Pugh, 1991)

## 3. Product Design Specification

For the product design specification activity, the crucial parameters, specifications and prerequisites will be listed in product design specification (PDS) table. The PDS is created during the issue definition action ahead of schedule in the configuration process. Most of the significant product design specification particulars are driven by consumer or industry needs. It is arranged to show what are the designer is trying to achieve and is an always a develaaaoping document. PDS is also subjected to revisions as the project move forward and as more new information are available. For the proposed multi-curved body armor, the PDS is formulated as in Table 1.

Table 1. Product design specification for multi-curved body armor

| **Product Design Specification** | | |
|---|---|---|
| **Multi-Curved Body Armor** | | |
| **Date: xx February 2015** | | |
| **Sheet: 01/01** | | |
| **Ref. No.** | **Requirements** | |
| **Rev. No.** | | |
| 1 | Dimension | |
| | 1.1 Maximum Length: 300mm<br>1.2 Maximum Width: 230mm<br>1.3 Maximum Thickness: 12mm | |
| 2 | Material | |
| | 2.1 Composite<br>2.2 Ceramic | |
| 3 | Safety | |
| | 3.1 Protection<br>3.2 Enclosure of interior components | |
| 4 | Installation | |
| | 4.1 Quick assembly<br>4.2 Easy assembly | |
| 5 | Manufacturing process | |
| | 5.1 Simple<br>5.2 Compression/Load<br>5.3 Heats | |
| 6 | Target Product Cost | |
| | 6.1 Low fabrication cost<br>6.2 Minimum maintenance cost | |
| 7 | Design | |
| | 7.1 Multi-curved<br>7.2 Tile | |

## 4. Conceptual Design

Conceptual design activities includes two phases namely the generation of possible solution which can fulfil the design specification and the assessment of the solution to match the PDS. Sapuan *et al* [8] reported that there are several methods that can be utilized by designer to create outline ideas to find many conceptual design solutions. Some of the methods are listed below:

a. Morphology method
b. Gallery technique.
c. Problem decomposition (Domain and Functional).
d. Brainstorming method (Classic,Visual,etc).

For this study, the Brainstorming method (Visual style) was selected to come up of the reasonable conceptual designs.