DESIGN AND ANALYSIS OF HARD BODY ARMOUR COMPOSITE MOULD SYSTEM

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ABSTRACT

The development of lightweight and low cost of hard body armour is under on-going attention by both manufacturers and users. In general, most hard body armour is made from metal, ceramic or composite. There are various methods to develop hard body armour such as manual layup, compression, resin transfer, slip casting, sand casting, hot pressing and injection moulding. However, for natural based reinforced composite where the reinforcement material is in powder or particulate form, such methods have to be specifically modified to achieve workability. This study presents a systematic design and fabrication process on hard body armour by using compression moulding method, where coconut shell powder was used as the reinforcement material in the composite system. Concept generation method was applied on developing the conceptual mould design. Three conceptual mould designs were proposed for flexible and hexagonal type of hard body armour. Based on the analysed data using weighted design method, the durability and manufacturability aspect were found as significant criteria to develop the mould. Further analysis such as fatigue life estimation was done to evaluate the durability, while machining time to measure the manufacturability on every concept design. Based on finite element analysis, hexagonal mould design number 3 was selected for prototype development due to its superior maximum stress of 33.7 MPa and total deformation of 10.72×10^{-6} m at compressing load of 784.8 kN, respectively. Meanwhile, flexible mould design number 3 was selected for prototype development due to its maximum stress value recorded and total deformation of 33.71 MPa and 4.6125×10^{-6} m, respectively. The fabricated hexagonal and flexible armour panels were subjected to ballistic test according to

the regulatory standards. From the results, hexagonal armour panel with areal density 27.2 kg/m^2 has a significant ballistic resistance to 9 mm FMJ ammunition impact which is equivalent to protection NIJ Level IIIA. Meanwhile, flexible armour panel with areal density 22kg/m^2 also equivalent protection NIJ Level IIIA.

ABSTRAK

Pembangunan baju kalis peluru yang ringan dan murah menjadi perhatian kepada pengeluar dan pengguna. Pada umumnya bahan baju kalis peluru diperbuat daripada besi, seramik atau komposit dimana proses pembuatanya melibatkan pelbagai teknik antaranya menyapu secara manual, mampatan dan pemindahan resin. Walau bagaimanapun, bagi bahan komposit semulajadi yang ingin diperkukuhkan, terutamanya bagi bahan yang berasaskan serbuk, teknik khusus diperlukan untuk mencapai tahap kebolehkerjaan dalam proses fabrikasi sebenar. Kajian ini ingin membentangkan pendekatan rekabentuk sistematik dalam pembuatan jubin serbuk komposit berasaskan serbuk semulajadi yang menggunakan kaedah acuan mampatan. Kaedah penjanaan konsep telah digunakan untuk menghasilkan konsep acuan jubin heksagon dan fleksibel dimana mempunyai sistem pelenting yang berbeza. Mengikut skala ukuran, ketahanan dan proses pemesinan adalah kriteria yang penting dalam pembangunan acuan. Seterusnya, analisis seperti anggaran hayat lesu telah dijalankan untuk menilai tahap ketahanan manakala anggaran masa pemesinan untuk mengukur tahap kesukaran proses pemesinan pada rekabentuk konsep. Berdasarkan daripada analisis acuan rekabentuk hexagonal, konsep nombor 3 hanya mengalami tekanan maksimum 33.7 MPa dan pada perubahan total 10.72×10^{-6} m jika dibandingkan dengan konsep lain. Pada masa yang sama, acuan rekabetuk fleksibel, konsep nombor 3 hanya mengalami tekanan maksimum 33.71 MPa dan perubahan total pada 4.6125×10^{-6} m. Ujian balistik telah dijalankan keatas kedua-dua panel perisai heksagon dan fleksibel, di mana panel ini melapasi piawaian yang ditetapkan. Berdasarkan dari keputusan balistik, panel perisai hexagon yang mempunyai

ketumpatan permukaan 27.2 kg/m^2 mampu memberi rintangan balistik 9 mm FMJ bersamaan perlindungan NIJ tahap IIIA. Manakala panel perisai fleksibel yang mempunyai ketumpatan permukaan 22kg/m^2 juga mampu memberi rintangan balistik bersamaan NIJ tahap IIIA.

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APPROVAL

I certify that an Examination Committee has met on **14th April 2017** to conduct the final examination of **Muhammad Azhar Bin A Bakar** on his degree thesis entitled '**Design and Analysis of Hard Body Armour Composite Mould System**'. The committee recommends that the student be awarded the degree of Master of Science (Mechanical Engineering).

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LIST OF ABBREVIATIONS

°F	Fahrenheit
°C	Celsius
AlN	Alumina Nitride
Al_2O_3	Alumina Oxide
B_4C-CaB_6	Boron Carbide-Calcium Hexaboride
BFS	Back Face Signature
B_4C	Boron Carbide
CSM	Chopped Strand Mat
CP	Cross Ply
CMM	Coordinate-Measuring Machine
CAD	Computer Aided Design
COEX	Coconut Shell Powder-Epoxy
FE	Finite Element
FMJ	Full Metal Jacket
GFRP	Glass Fiber Reinforced Plastic
GDNR	Grafted Depolymerized Natural Rubber
hp	Horse Power
kN	Kilo Newton
kW	Kilo Watt
kg	Kilogram
mm	Millimetre
MPa	Mega Pascal
NR	Natural Rubber

NC	Numerical Control
NIJ	National Institute Of Justice
PDS	Product Design Specification
rpm	Revolution Per Minute
RBSC	Reaction-Bonded Silicon Carbide
RTM	Resin Transfer Moulding
RFI	Resin Film Infusion
SiC	Silicon Carbide
Si_3N_4	Silicon Nitride
s	Second
TiB_2	Titanium Boron
UHMWPE	Ultrahigh Molecular Weight Polyethylene
UD	Unidirectional
V_{50}	Velocity Limit

CHAPTER 1

INTRODUCTION

1.1 Background

The ancient tribe used various types of material and design to protect themselves from any dangerous situations especially from wild animal's attack that can cause serious injury. History recorded that animal hides and plant materials were used as protective clothing by cavemen. Later, the improvement on the design of the protective clothing can be seen as materials such as wood or metal were used to strengthen the protection. As piece of evidence, during Ancient Rome and Medieval Europe eras, soldiers covered their torso with metal plates to reduce the penetration effect during battle. Additionally, body armour had become lighter and better as the technology have continuously improved since the 1500's era (Absolon and Thatcher, 2011).

During World War I, various countries have contributed to the development of armour with adequate protection. In 1915 until 1918, several armour designs were developed but on experimental basis as it were never tested in actual battle.

The lightweight type of body armour was introduced during World War II (1939 - 1945). In United State of America, M-12 vest was designed to protect vital organs against explosive fragments and mainly worn by aircrew members of bomber aircraft for missions. Otherwise, in Soviet Union, SN-42 vest was designed and mostly worn by ground infantry units in urban combat to protect themselves against the 9 mm projectile. The development of M-12 vest was made from multiple layers of woven ballistic nylon fibre, contained aluminium plates, and weighed around 5.4 kg while the SN-42 vest employed two layers of pressed steel sheets and weighed about 3.5 kg. However, both designs were still insufficient to protect the user against most gun and rifle (Heard, 2008).

Body armour is designed to reduce the penetration impact in variety scenarios. It is categorized under two types, which are soft body armour (Figure 1.1a) and hard body armour (Figure 1.1b). Typically, soft body armour is fabricated from advance fabric. In military or civil application, soft body armour is made from woven fabrics with high-strength, due to its excellent performance in mechanical properties like high specific strength and stiffness, and high resistance towards corrosion. The mechanism behind the usage of woven fabric is when the bullet hit the soft body armour panel and the movement of impact is translated into stretching force to slowing down the bullet velocity. In the current market, there are a few brands of fibre material available such as Kevlar, Dyneema, Twaron, and Zylon with all of them offering different qualities.

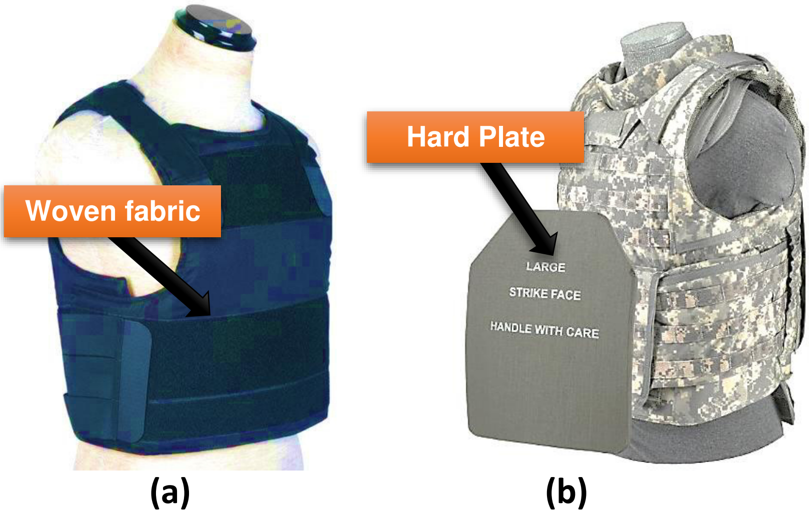

Figure 1.1: Type of body armour (a) Soft body armour. (b) Hard body armour. ("BAE Systems Wins $75 Million Order for Protective Hard Armour Inserts," 2012).

Practically, hard body armour is embedded by plates to give extra protection against higher level threats. This concept has been applied in the mail chain armour since the medieval era where soldier inserts small additional plates or discs of iron into the mail chain to protect vulnerable areas as shown in Figure 1.2. Today, based on the original concept, it is constructed by inserting plates into the ballistic vest either inside or outside of the soft body armour to provide additional protection. The hard body armour plates have various types of material such as metal, ceramic and composite to provide optimum performance to the user.

Figure 1.2: Russian plated mail armour (Absolon and Thatcher, 2011).

Hard body armour possesses excellent puncture resistance, due to their tough and rigid properties. Over the last decade, the use of metal in body armour has increased exponentially (Teng *et al.*, 2008). The metal plates response during impact by deforming plastically under the force transferred from the target point. The main disadvantage of metal plates is relatively high density and unrealistic for routine use, especially for police operation. On the other hand, there is another potential candidate which is titanium alloys but its relatively high cost.

Most of the ceramic plates that are being used in the body armour provide a Level III protection (U.S. Department of Justice, 2008). The plate armour should withstand 7.62 mm or 5.56 mm ammunition at speed 850 m/s. Figure 1.3 shows penetration mechanism of ceramic material during impact where the energy was translated through fracture. Nowadays, several of ceramics are used as the hard plate facing the projectile. Alumina, silicon carbide and boron are the most readily available and cost-effective materials (Shockey *et al.*, 1990). High hardness