PAPER • OPEN ACCESS

Analysis of Bulletproof Vest Made from Fiber Carbon Composite and Hollow Glass Microsphere (HGM) in Absorbing Energy due to Projectile Impact

IOP Conf. Series: Materials Science and Engineering **506** (2019) 012001 doi:10.1088/1757-899X/506/1/012001

Analysis of Bulletproof Vest Made from Fiber Carbon Composite and Hollow Glass Microsphere (HGM) in Absorbing Energy due to Projectile Impact

Muhammad Anhar Pulungan[1], Sutikno[2], M S M Sani[3]
[1]Mechanical Engineering Department, South Polytechnic Aceh (POLTAS), Aceh 23751, Indonesia
[2]Mechanical Engineering Department, Institut Teknologi Sepuluh November (ITS), Surabaya 60111, Indonesia
[3]Advanced Structural Integrity and Vibration Research (ASIVR), Faculty of Mechanichal Engineering, University Malaysia Pahang (UMP), 26600 Pekan, Pahang Malaysia

*Corresponding author: anhar.240205@gmail.com

Abstract. Bulletproof vest serves as a barrier and simultaneously absorbing the impact energy of a projectile shot from a firearm so it could not injure the users. Manufacture of lighter bulletproof vests with good absorbent of impact energy, is expected, because it supports the mobility and safety of its users. In this study, a composite composed of an epoxy matrix with a 16% Hollow Glass Microsphere (HGM) and carbon fiber reinforce to be implemented in a bulletproof vest. The objective of this research is to analyze the bullet-proof vests made of epoxy matrix composites with reinforcement in the form of HGM and carbon fiber through simulation with finite element method. Simulations with Ansys conducted in accordance with NIJ Standard 0101.06 from the U.S. Department of Justice, where the projectile initial velocity of 426 m/s for the category IIIA class weapon with a kinetic energy of projectile amounted to 528.37 Joules. The simulation with Ansys was performed by varying the thickness of bulletproof vests to obtain optimum thickness. The outcome of this research is a bulletproof vest that absorbs the impact energy of the projectile, so that the energy transmitted to the body is smaller than 170 Joules. Having obtaining the optimum thickness of bulletproof vest, an experimental verification will be performed to validate the simulation results. In the simulation results showed that a bullet proof vest with a thickness of 20 mm has been able to meet the standards of Major General Julian S. Hatcher, a U.S. Army ordnance expert with great energy generated at 138.77 Joules.

1. Introduction

Technology is evolving rapidly in increasing of time, this resulted in the need of amassed usage of an alternative material because of the unbalanced availability of material now days. In the industrial world, the science of metal is very important in all aspects. As aspects of the usage of appropriate materials costs, the safety factor manageable maintenance and efficiency [1]. In the automotive industry, aerospace and military response to the global issues of material crisis as a challenge, and therefore a lot of equipment are being made with high efficiency lightweight material [2]. One that needs to be developed is the body of a lightweight material. By reducing the weight of a product, the lower the

IOP Conf. Series: Materials Science and Engineering **506** (2019) 012001 doi:10.1088/1757-899X/506/1/012001

energy consumption, so as to contribute to the issue of energy crisis being faced around the world.

One of the materials used in the manufacture of a bulletproof vest on the inside of the light is a composite material. The advantages of this material are the strength to weight ratio that is higher than the metal material. In addition of considering the physical properties such as low density, the mechanical properties of the composite material should also be considered because of the associated safety of users of the bullet-proof vests and able to provide protection against impact loads users from working [2-4]. Bulletproof vest is a protective clothing that is widely used in the military world. Bulletproof vest protects the body the chest, stomach and backbone. Backbone and chest are major parts of the body that protects the vital organs of man. Bulletproof safety vest is comfortable and has passed the requirements of Hatcher's Notebook (1962) by Major General Julian S. Hatcher, a U.S. Army ordnance expert [5-6].

Hollow Glass microspheres (HGM) is a glass ball microscale applied for; research, medical, and consumer products in various industries. The glass balls generally have diameters ranging from 1 micron to 1000 micron. Hollow Glass Microsphere have a range of diameters from 10 microns to 300 microns. HGM is usually used as a filler for composite materials, the advantages of this HGM among others:

- HGM has a density of small.
- Low thermal conductivity.
- The resistance to compression loads well.

HGM is a type of particle amplifier. HGM is a sphere made of glass with a certain thickness and has a hole in it containing an inert gas. HGM has many advantages, for example, has a density that excels because it has a hole so suitable for use to produce light material combinations (composite). HGM type IM30K is made of soda-lime-borosilicate glass with density of 0.6 g/cc, and an average diameter of each particle is 18 microns. HGM has high isostatic crush strength which is 28000 psi [7-9]. Table 1 shows the types of HGM IM30K that will be used in this study.

Table 1. Specifications HGM IM30K [10]

Property	**IM30K**	
Shape	*Hollow spheres with thin walls*	
Composition	*Soda-lime-borosilicate glass*	
Color, Unaided Eye	*White powder*	
Physical Properties	**IM30K**	**Test Method**
Isostatic Crush Strength	28000 psi	3M QCM 14.1.8
True Density	600 kg/m^3	3M QCM 14.24.1
Packing Factor (bulk density to true particle density)	63%	
Oil Absorption	33.5	ASTM D282-84 *of polymer additive*
Softening Point	600^{0}C	
Flotation Density	90%(in volume)	3M QCM 37.2
Volatile content (by weight)	0.5 % max	3M QCM 1.5.7
Alkalinity (miliequivalents)	0.5 mEq	3M QCM 55.19gr/max
pH(5% loading in water)	9.5 %	ASTM D3100-1982
Diameter	18 µ	3M QCM 193.0

Carbon fiber is one form of composite materials. Composite materials, which are taken from the English term composition materials or shortened to composite materials, is a material made of two or more materials making up mutually having different physical and chemical properties, that will produce a material characteristic different from the materials constituent. Carbon fiber composites are one type of composite material using carbon fiber as one constituent [11-13].

This study aimed to make a bulletproof vest with a combination of carbon fiber and 16% HGM-epoxy that is able to absorb all the impact energy and reduce weight so as to produce a lightweight vests, which will increase movement while on duty, and of course to reduce the penetration of bullets in accordance with the testing standards NIJ Standard 0101.06 that is equal to 44 mm. This study will also analyze the effect of the addition of carbon fiber as reinforcement in reducing the impact waterwheel that will be accepted by the body, thereby reducing the level of injury that would be suffered by the user [14-15].

2. Research Methodology

Stages of research conducted is referring to the flow chart below which shows that the process occurs from several stages and test so that the best results are obtained as shown in the figure 1:

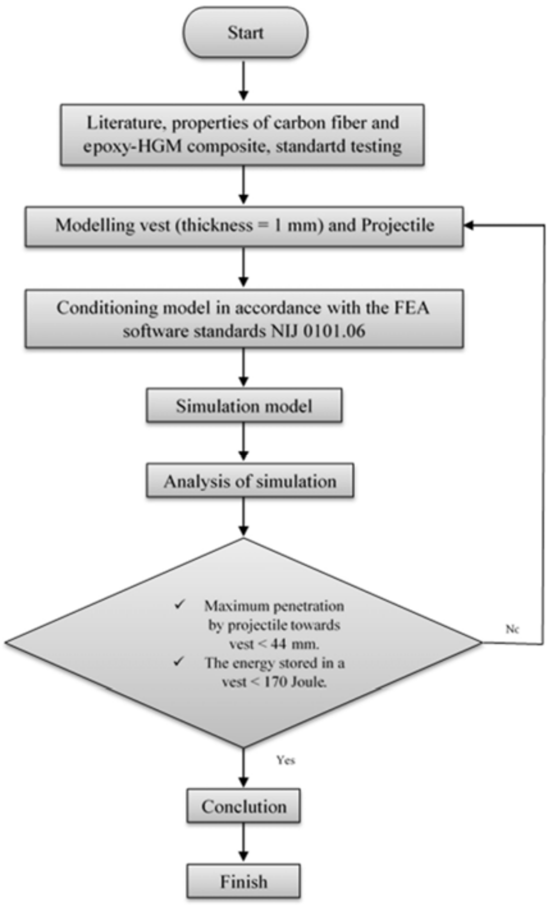


Figure 1. Flowchart research

In figure 2 shows the process that occurs in the ansys software starting from modeling to the results .
In this procedure includes several stages [16-17], namely:

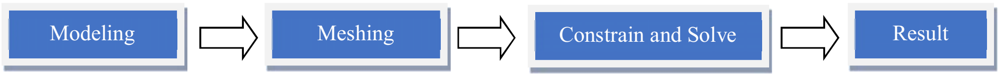


Figure 2. Simulation procedures

2.1 Conditioning of impact test and the absorption of kinetic energy
In figure 3, shows the selection of material types to be used in this study which aims to provide the right material properties of specimen of material used [18-19]

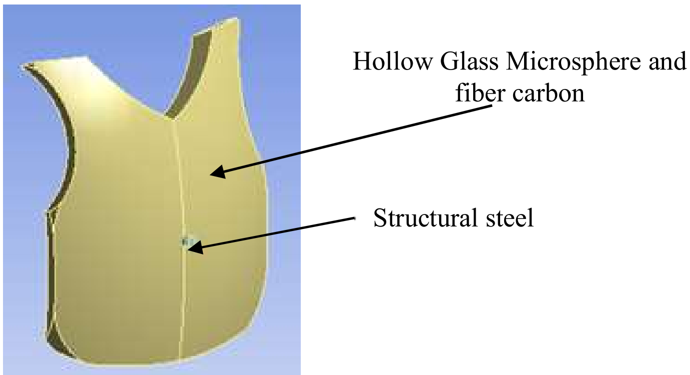


Figure 3. The choice of material in the vests and bullet models

2.2 Conditioning Meshing.
Figure 4 shows how the selection process is very important in using Ansys, in this study using the smallest meshing value is aim to get the better results.

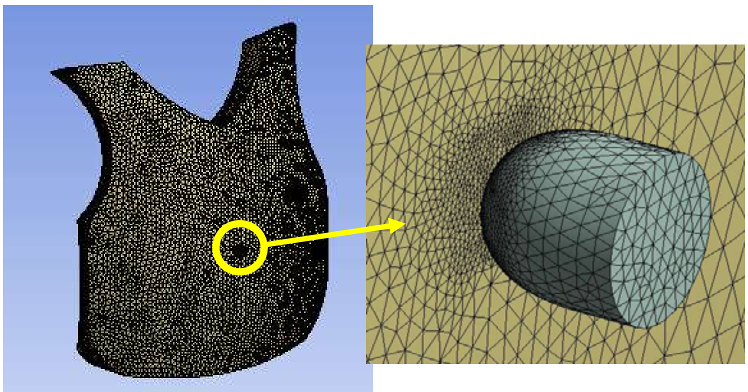
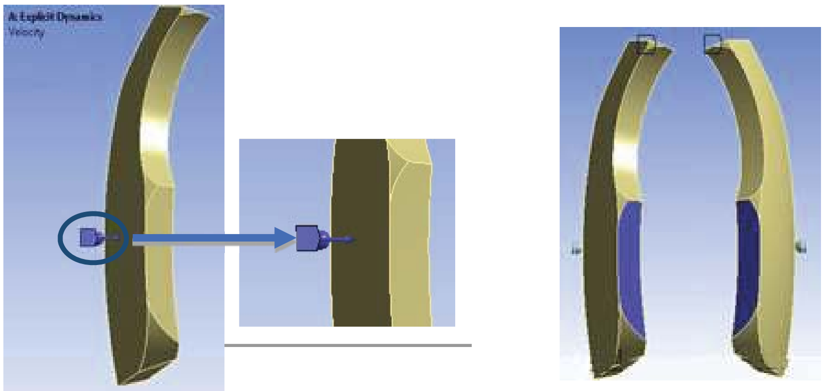


Figure 4. Meshing selection of the impact test

2.3 Conditioning of load and fixed support on the model
Figure 5 shows that the load in figure 5.a aims to give impact capability to the bullet by adding the speed of the bullet according to the standart test using the III-A type of weapon that is 426 m/s. Then in figure 5.b, it provides fixed support on both sides of the vest design which aims as a barrier so that during the collision the vest design remains in the desired position.

IOP Conf. Series: Materials Science and Engineering **506** (2019) 012001 doi:10.1088/1757-899X/506/1/012001



(a) (b)

Figure 5. Design of the bulletproof vest (a) Provision of the burden of a speeding bullet 426 m/s (b) fixed support

3. Results and Discussion

Bulletproof vest deforms when receiving impact and deformation varies between different thicknesses of vest. The smallest deformation happens to the vest with the highest thickness, which is 20 mm followed by a bulletproof vest thickness of 15 mm and the highest deformation is the vest with thickness of 1 mm, as shown in table 2 below.

Table 2. Specifications and Energy owned by the vest and the bullet.

No	Thickness (mm)	The depth penetration (mm)	Kinetic Energy of Bullets (J)	Kinetic energy Vests (J)	Internal energy Vests (J)
1	1	44.71	528.37	270.99	251.99
2	5	21.95	528.37	258.10	255.71
3	10	12.39	528.37	228.49	269.63
4	15	9.81	528.37	198.29	291.98
5	20	5.54	528.37	138.77	348.27

Figure 6 shows that with the increasing of thickness, the ability of a projectile to penetrate the vest is also decreases. NIJ Standard 0101.06 from the U.S. Department of Justice stated that maximum deformation allowed for a safe to use bulletproof vest is amounted to 44 mm. At a thickness of 1mm projectile capable of penetrating the vest as far as 44.71mm, while the thickness of 5 mm, 10 mm, 15 mm and 20 mm, the deformation's depth less than 44 mm is equal to 21.95 mm; 12.39 mm; 9.81 mm; and 5.54 mm respectively. It can be concluded that the vest with a thickness of 5 mm, 10 mm, 15 mm and 20 mm has met the standard of NIJ Standard 0101.06 from the U.S. Department of Justice.

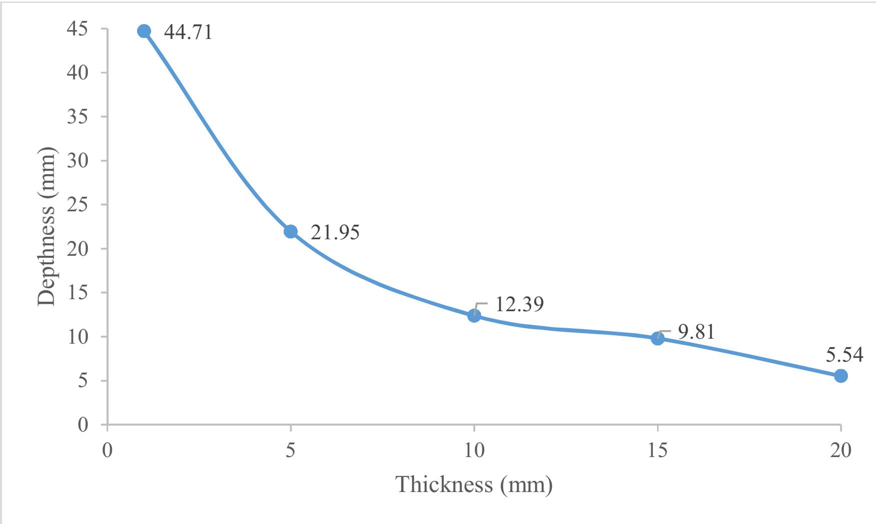


Figure 6. Graph of the projectile penetration decreased in increasing of thickness

In **Figure 7** below shows that with the increasing thickness of the vest, the bullet's kinetic energy that converted into the vest's kinetic energy is decreased. The kinetic energy received by the vest can still burden the user with load. In a bulletproof vest with a thickness of 1 mm, maximum kinetic energy accepted is 270.99 joules, a thickness of 5 mm maximum kinetic energy accepted is 258.10 joules, while for thickness 10 mm, 15 mm and 20 mm, the maximum kinetic energy accepted are 228.49 joules, 198.29 joules and 138.77 joules respectively. Hatcher's Notebook (1962) by Major General Julian S. Hatcher, a U.S. Army ordnance experts declared energy of 170 joules can cause paralysis in humans, so it can be concluded that the vest with a thickness of 20 mm has met these standards.

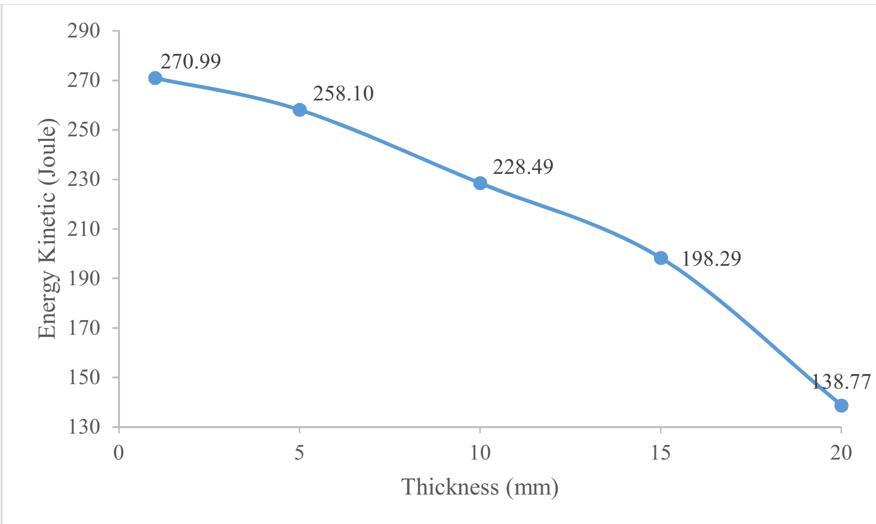


Figure 7. Graph increase in kinetic energy in a bulletproof vest

Figure 8 below shows that with increasing thickness, the kinetic energy of the bullet is converted into internal energy vests also increased. At vest with a thickness of 1mm the internal energy resulted id 251.99 joules, and the vest with a thickness of, 5 mm, 10 mm, and 20 mm, the internal energy resulted are, 255.71 joules, 269.63 joules, 291.98 joules, and 348.27 joules respectively.

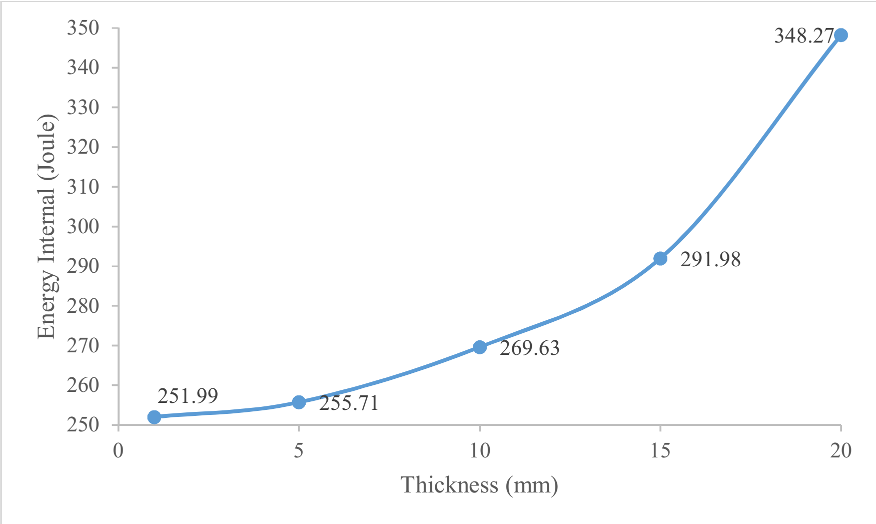


Figure 8. Graph showing the increment of the internal kinetic energy in a bulletproof vest.

4. Conclusions

Based on the simulation, it is concluded that:

i. The bulletproof vest with a thickness of 20 mm produces 138.77 joules of energy, which is safe to use. Based on the reports of Major General Julian S. Hatcher, a U.S. Army ordnance experts note that the total energy of 170.2 joules is capable of causing injury and able to paralyze the victim.
ii. The bulletproof vests with a thickness of 5, 10, 15, and 20 mm are safe to be used. Based on the NIJ standard 0101.06, penetration of the projectile against a bulletproof vest may not exceed 44 mm.
iii. A vest that is safe to be used is a vest with a thickness of 20 mm. Based on two of these references, (standard NIJ and Major General Julian s.)
iv. In this study, a bulletproof vest with a thickness of 20 mm is able to absorb the kinetic energy of the projectile in the amount of 138.77 joules of energy. The kinetic energy of the projectile will be transferred to the bullet-proof vests and is converted into kinetic energy and internal energy in a bulletproof vest.

References

[1] A Trofimov, L. Pleshkov, H. Back 2007 Hollow glass microsphere for high strength composite cores *Alchemie Technology* vol 50 (44-46) pp 48-50
[2] M S M Sani, N A Z Abdullah, S N Zahari, J P Siregar and M M Rahman 2016 Finite element model updating of natural fibre reinforced composite structure in structural dynamics *MATEC Web of Conferences* 83(03007)
[3] A Tasdemirci, G Tunusoglu and M Güden 2012 The effect of the interlayer on the ballistic

performance of ceramic/composite armors: Experimental and numerical study *International Journal of Impact Engineering* vol 44 pp1-9

[4] D Bürger, A Rocha de Faria, S F M de Almeida, F C L de Melo, Maurício V. Donadon 2012 Ballistic impact simulation of an armour-piercing projectile on hybrid ceramic/fiber reinforced composite armours *International Journal of Impact Engineering* vol 43 pp 63-77

[5] National Institute of Justice 2016 Development and evaluation agency of the United States Department of Justice, NIJ 0101.06

[6] US Patent Protective body armor garment shell *US5331683 A*

[7] F Y Arista 2013 Pengaruh Penambahan HGM terhadap sifat fisik dari komposit dengan matrix epoxy *Institut Teknologi Sepuluh Nopember*

[8] Hindun 2015 Analisa komposit matriks epoxy dengan penguat HGM untuk pembuatan bumper depan kendaraan *Institut Teknologi Sepuluh Nopember*

[9] Z Q Lutfianisa 2015 Analisa kemampuan rompi anti peluru yang terbuat dari komposit hgm 16% dalam menyerap energi akibat *impact* proyektil *Institut Teknologi Sepuluh Nopember*

[10] W Ritonga 2017 Pengaruh variasi fraksi volume, temperatur curing dan post-curing terhadap karakteristik tekan komposit epoxy - HGM IM30K *Jurnal Teknik Institut Teknologi Sepuluh Nopember* vol 6(1) pp 196-200

[11] H A Maples, S Wakefield, P Robinson and A Bismarcka 2014 High performance carbon fibre reinforced epoxy composites with controllable stiffness *Composites Science and Technology* vol 105 pp 134-143

[12] W A de Morais, J R M d'AlmeidaI, L B Godefroid 2003 Effect of the fiber reinforcement on the low energy impact behavior of fabric reinforced resin matrix composite materials *Journal of the Brazilian Society of Mechanical Sciences and Engineering* vol25(4) pp 325-328

[13] S K Mazumdar 2001 Composites Manufacturing: Materials, Product, and Process Engineering *CRC Press: United Kingdom* First Edition

[14] National Institute of Justice 2016 Development and evaluation agency of the United States Department of Justice, NIJ 0101.06.

[15] US Patent Cartridge for small arms 5094169

[16] M S M Fouzi, K M Jelani, N A Nazri and M S M Sani 2018 Finite Element Modelling and Updating of Welded Thin-Walled Beam *International Journal of Automotive and Engineering* vol 15(4) pp 5874-5889

[17] N A Abdullah, M S M Sani and I Zaman 2017 Correlation of Structural Modal Properties of Go-Kart Frame Structure Using Different Type of Joint in Finite Element Modeling *Advanced Science Letters* vol 23(1) pp 11315-11319

[18] M N M Merzuki, M R M Rejab, M S M Sani, B Zhang, M Quanjin and W Rafizi 2019 Investigation of modal analysis on glass fiber laminate aluminium reinforced polymer: An experimental study *IOP Conference Series: Materials Science and Engineering* vol 469 (013165)

[19] M S M Fouzi, M S M Sani and Y Muchlis 2019 Finite Element Modelling and updating of welded joint for dynamic study of exhaust structure *IOP Conference Series: Materials Science and Engineering* vol 469 (012099)