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Analysis of Energy Absorption of Soft Body Armor with Experimental Method and Finite Element Method Using STF (Shear Thickening Fluid) Composite Material

A.D. Putra[a*], D.I. Tsamroh[b], B.C. Tjiptady[a]

[a]*Department of Mechanical Engineering, Faculty of Science and Technology, Universitas Islam Raden Rahmat Malang, Jalan Mojosari 2, Kepanjen, Malang, Indonesia*
[b]*Department of Mechanical Engineering, Faculty of Engineering, Universitas Merdeka Malang, Jalan Raya Terusan Dieng 62-64 Malang, Indonesia*
**agus_dwi_putra@uniramalang.ac.id*

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ABSTRACT

Body armor is a personal protective equipment or armor for warriors that has existed since Roman times to the present day. The function of body armor is to protect the body from attacks by foreign objects by absorbing energy. Body armor must have ballistic resistance and stabbing resistance, but body armor that is often found usually has a high anti-ballistic level but is low in receiving stabbing attacks. STF (Shear Thickening Fluid) is a composite material which is unique in that the viscosity level can change drastically so that the liquid dispersion becomes solid and allows for increased stabbing resistance. This research was started by preparing a Kevlar sample which was then mixed with STF and then subjected to a tensile test to obtain materials properties that are useful for simulating FEM. The simulation is intended to analyze the rate of energy absorption that occurs in the sample. The results show that the rate of absorption of the kinetic energy of the bullet is absorbed at a viscosity of 87%. The small energy that occurs is also absorbed in the form of frictional resistance with a value of 11.9%. The comparison results identified show that in cases 1-3 the percentage of viscosity is high so that it is viscous, whereas in case 4 the direct reflection of the viscosity is low so that it is close to liquid.

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Keywords: Body Armour, Komposite, Shear Thickening Fluid, Ballistic, Stabbing

1. Introduction

In war or training, a soldier usually wears a protective vest which is officially called Body Armor. Body Armor is useful in protecting a soldier's body from ballistic attacks or sharp objects, thereby minimizing the occurrence of injury [1]. Body Armor has been used since ancient times, precisely during the reign of the ancient Romans [2]. The vital function of Body Armor is to resist and stop the penetration of foreign objects into the body and can absorb impact energy [3]. Existing history demands that Body Armor must have two advantages, namely being able to withstand ballistic attacks and being anti-stabbing.

In general, Body Armor is made from materials that are layered between 10 layers and 50 layers depending on the specified needs with an average weight between 3-5 kg [4][2]. Several discoveries prove that not all Body Armor has 2 properties, namely anti-ballistic and anti-stabbing [5]. Many Body Armors have good anti-ballistic properties but are not good at receiving stabbing attacks [6], Thus, Body Armor must be required to be able to withstand these 2 types of attacks. One of the obstacles that makes Body Armor less good at receiving stabbing attacks is the difficulty in increasing stabbing resistance because stabbing resistance is different from ballistic resistance. [7]. This is influenced by differences in impact speed and sharpness of different attacking objects so that

Body Armor which is widely sold on the market still has a weakness, namely that it is not good at absorbing stabbing resistance [8].

One material that is attracting attention as a candidate for making Body Armor is Shear Thickening Fluid (STF). The advantage of STF is that it has unique properties in reducing impact attacks [9][10]. STF is a non-Newtonian fluid which has the property or behavior of shear thickening which is triggered by a sudden increase in shear rate, this is capable of causing the colloid dispersion to become concentrated and a sudden increase in viscosity [11]. This change causes the liquid dispersion to change to a solid, making it possible to increase stabbing resistance [12][13]. Previous research also found that STF was able to improve the performance of impact fabric panels against high and low speed impacts [3][14]. The findings and basic theory that have been discussed, this research focuses on increasing the stabbing resistance of Body Armor with STF mixing materials which are then tensile tested to determine the material properties which are then analyzed using the Finite Element Methods method.

2. Methodology of Research

The first step in this research was material preparation, tool preparation, and STF creation and fabrication.

2.1. Materials

Details of the materials used in this research include Kevlar sheets, Polyethylene Glycol 200, SiO_2, and Ethanol.

2.2. Tools

The tools used in this research include a magnetic stirrer, ultrasonic homogenizer, oven, yarn out test, computer.

2.3. STF manufacturing and fabrication

After the tools and materials have been collected, the next stage is making the STF. Making STF is by mixing Polyethylene Glycol (PEG 200) and Silica (SiO_2) according to the concentration in stages, which is then coated on Kevlar fabric as in Figure 1.

Figure 1. Kevlar with STF coated

After making Kevlar sheet samples with STF coating, the next stage is testing the samples with thread tensile tests and friction coefficient tests. This test is the basis for inputting materials properties so that they can be entered into simulation software to be tested using the finite element method.

2.4. Kevlar Modeling

The design in this research can be seen in Figure 2. The fabric sheet is formed with a thickness of 0.2 mm and a length of 2 mm. In this modeling the thread is formed as a membrane using Abaqus with 4 node meshing model M3D4R. This approach can reduce computation timing by maintaining the accuracy of mathematical calculations.

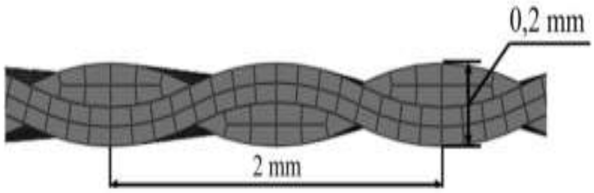

Figure 2. Fabric Modeling

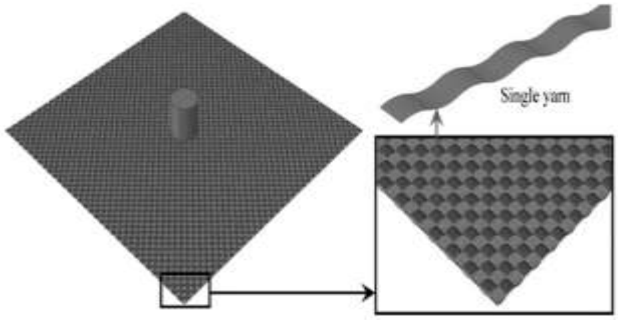

Figure 3. Element Modeling

The Kevlar fabric used is Kevlar with a 600 denier yarn content where the yarn density is 34 yarn/inch. Then each yarn has 400 filaments with a diameter of 12 micro m and a density of 1440 kg/m^3.

2.5. Kevlar STF composite modeling

The ready Kevlar fabric is then modeled by adding an STF layer. The STF layer is placed in the middle or inner part of the kevlar so that it can absorb maximum energy. Kevlar is placed on the outside and inside so that it can be coated perfectly with two layers of each layer. Kevlar modeling with STF can be seen in Figure 4.

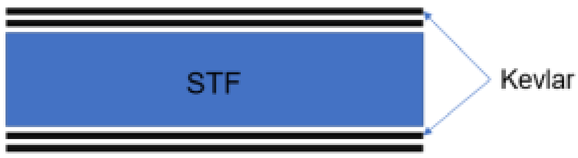

Figure 4. Illustration of STF Modeling

3. Result and Discussion

The results of this research are divided into several parts which will be described as follows.

3.1. Kevlar mechanical properties and friction coefficient

The results of the Tensile test can be seen in Figure 5 in graphic form. Based on the graph shown in Figure 5, the elastic modulus value for the yarn is 76 MPa, while the ultimate stress is 3.1 GPa. Then the density of Kevlar was found to be 1440 kg/m^3 with a poison ratio of 0.2. The coefficient of friction between threads is 0.21.

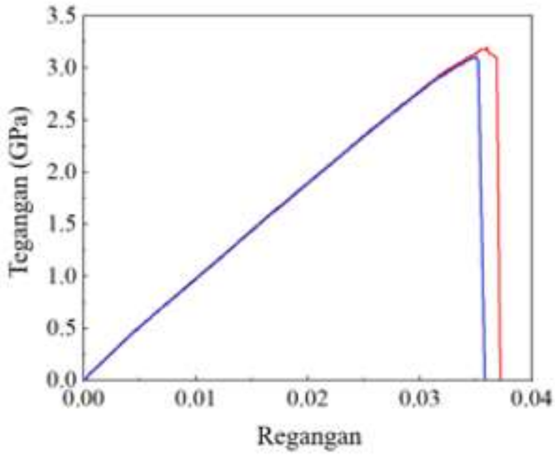

Figure 5. Tensile Test

3.2. Geometry model validation

The geometric model that has been created is validated using experimental methods. Kevlar with dimensions of 50 cm x 50 cm was coated with four layers and shot with a cylindrical steel projectile with a diameter of 5.6 mm and a mass of 1.1 g. The difference in kinetic energy of the bullet before and after passing through the fabric is measured to obtain the residual energy absorption value []. The experimental results of testing this model can be seen in Figure 6. Figure 6 proves that the simulation and experimental results differ by less than 5% and it can be said that the geometric or computational model is suitable for presenting experiments or it can be said that the model is accepted.

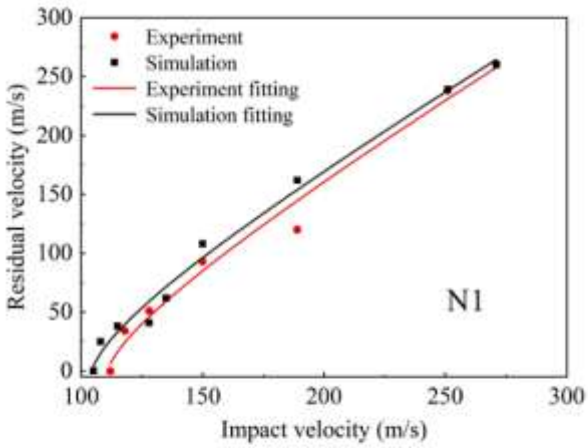

Figure 6. Comparison of Simulation and Experiment

3.3. Energy absorption

Energy absorption by composites with STF has been carried out using numerical simulations where the bullet speed is set at 244 m/s. In Figure 7 it can be observed that there is a change in time and a change in the center point and the projectile speed is also found for the five cases.

In the plot of time compared to the target speed of the composite it can be observed in cases 1-3. Cases 1-3 almost all have similar or almost the same trend curve diagrams. Meanwhile, in case 4, a trend was found where there was the highest displacement compared to case 1, case 2, case 3, and case 5. In case 5, the midpoint displacement occurred between cases 1-3 and case 4. Plot of time compared to speed in case 4 different between other cases of viscosity. This difference is triggered by the penetration of 2 layers or composite 8d images. From several variations of viscosity testing, the first three variations show similar deformation configuration results and can even be said to be similar where STF behaves like solid deformation. In the case of 4 STF behaves more like a liquid because the viscosity results can be said to be very low and changes locally.

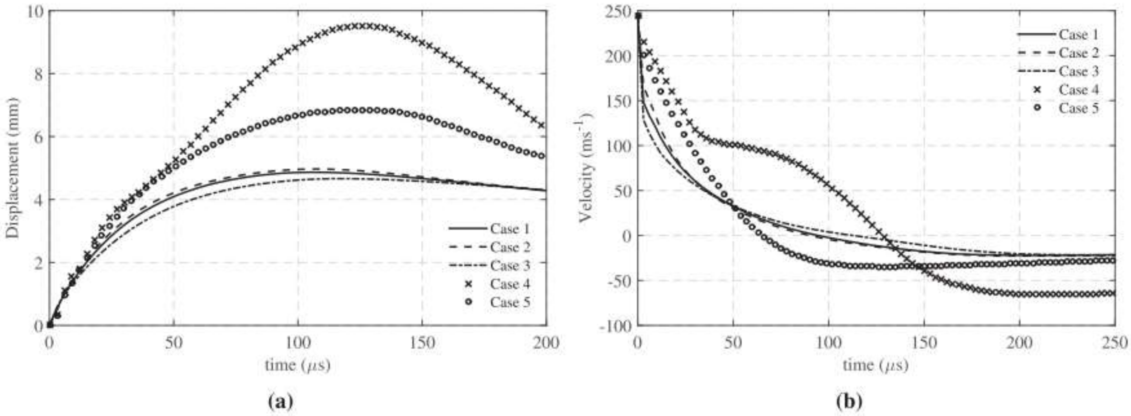

Figure 7. Impact point displacement and variation velocity: (a) impact point displacement; (b) bullet speed

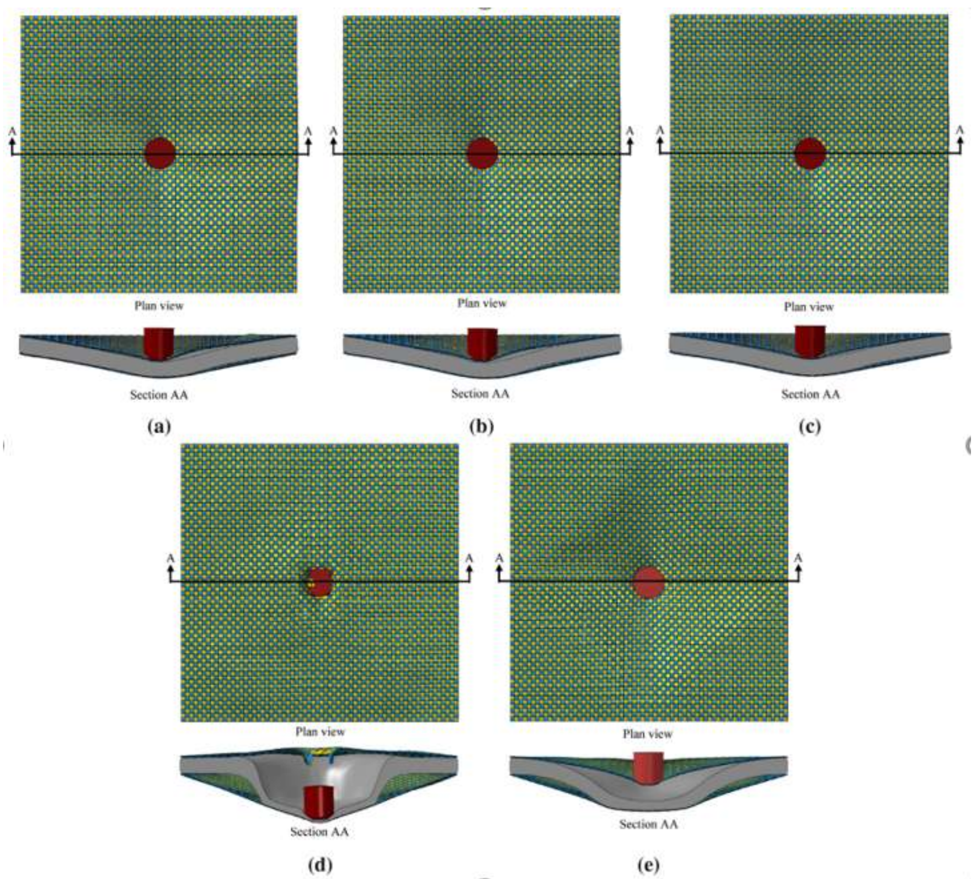

Figure 8. Deformation by Shot: (a) case 1; (b) case 2; (c) case 3; (d) case 4; and (e) case 5

In terms of energy absorption rate, the process of energy absorption rate is presented in Figure 9. The results show that almost the majority of the kinetic energy rate of the bullet is absorbed at a viscosity of 87%. The small energy that occurs is also absorbed in the form of frictional resistance with an absorption value of 11.9%. The identified comparison results show that in cases 1-3 the percentage of viscosity is high so that it is viscous and not liquid compared to case 4. This viscosity level shows how important the viscosity level of the STF is that receives a dynamic response to the Kevlar STF target. Case 4 shows the viscosity is low or can be said to be close to liquid so it can be said that it is a direct reflection of low viscosity at high strain rates.

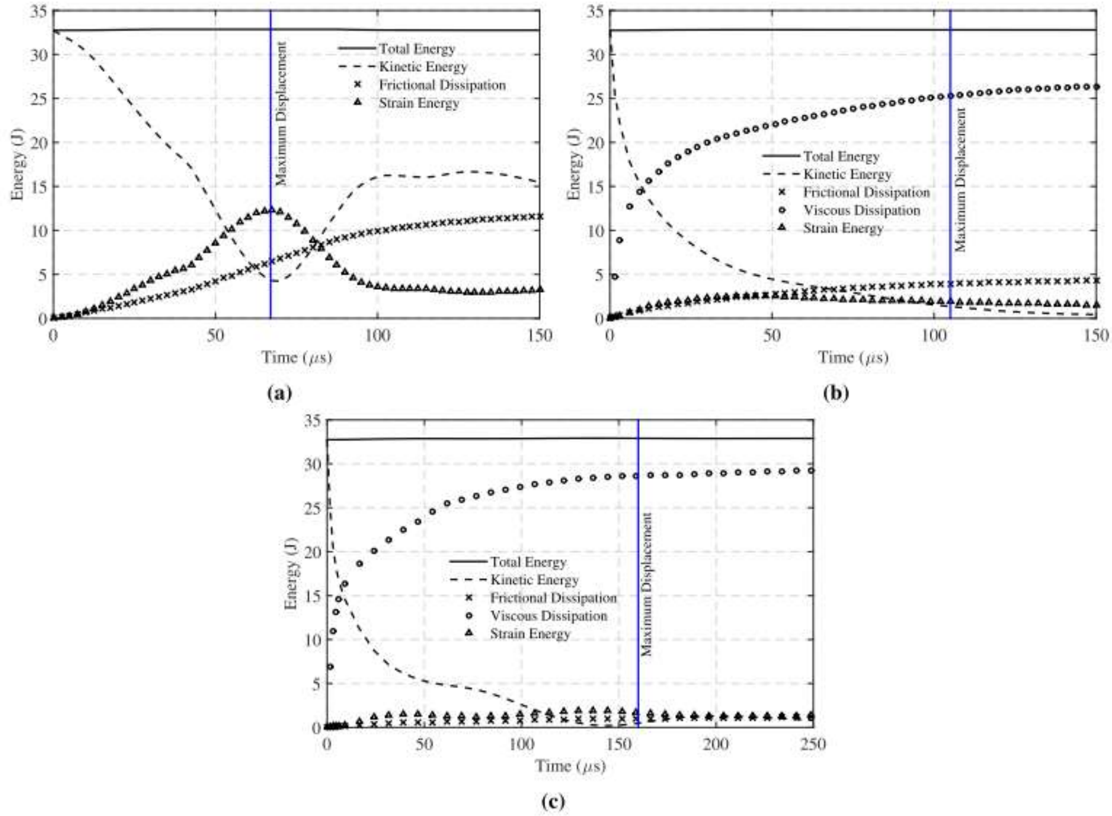

Figure 9. Energy Distribution: (a) 4 target layers; (b) 2 top layers; and (c) bottom layer

4. Conclusion

The results of the yarn tensile test showed that the modulus of elasticity was 76 MPa, while the ultimate stress was 3.1 GPa. Then the density of Kevlar was found to be 1440 kg/m^3 with a poison ratio of 0.2. The coefficient of friction between threads is 0.21.

Then the energy absorption by the STF composite shows that most of the kinetic energy rate of the bullet is absorbed at a viscosity of 87%. The small energy that occurs is also absorbed in the form of frictional resistance with a value of 11.9%. The identified comparison results show that in cases 1-3 the percentage of viscosity is high so it is viscous, whereas in case 4 the direct reflection of low viscosity at a high strain rate makes it close to liquid.

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