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Author 3 : Anindito Purnowidodo
Authot 4 : Agus Suprapto
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UDC 621

Energy absorbers on the steel plate – rubber laminate after deformable projectile impact

Helmy Purwanto, Rudy Soenoko, Anindito Purnowidodo, Agus Suprapto

The ability of energy absorption can be used to measure the strength of material against ballistic impact. This paper aims to analyze the rubber plated energy absorption plate that was shot with deformable projectiles. This study was conducted using numerical simulations based on finite element that have been verified with experimental results. The simulation setting on steel plate with different hardness with the addition of rubber thickness prepared as ballistic test panel. Manufacturing between layers made non fix with back plate. Panel shot by using 5.56x 45 mm deformable caliber bullet with a distance of 15 m of normal attack angle. Finite element code with Johnson-Cook and Mooney-Rivlin elasto-plastic material model was employed to perform the simulation study. Simulation results show the energy due to ballistic impact received and absorbed by the panel rises significantly shortly after the collision until reaching a certain number on a single plate where energy will decrease because the projectile successfully penetrated the plate. While on a layered plate, after the projectile succeeded in penetrating the front side plate, the absorption energy reached the maximum number and then remained constant, which caused the *projectile not to be able to penetrate the next layer. These findings indicate that the addition of rubber with a layered structure is able to absorb energy ballistic impact*

Keywords: Energy absorber, hard plate, soft plate, ballistic laminate plate, rubber, ballistic impact, simulation

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1. Introduction

Defense and security play an important role in state sovereignty. One of the most common defense equipment used in the military world is combat vehicles. Combat vehicles are special vehicles equipped with combat equipment and must be able to withstand the opponent's attacks. The success of combat vehicles is in the completion of defense and defense missions [1].

Material on combat vehicles in general is a steel plate. Steel is used because it has characteristics that can be strengthened, easily shaped and can form a structure. Steel is easily made and also has the nature of protection against ballistics. Ballistics is the study of the acceleration of moving objects, in modern ballistics science it is further defined as the study of the force, motion and impact of a projectile fired from a weapon [2]. Projectile clash with the plate resulted in very high strain on the narrow area [3].

Ballistic resistance is not only influenced by target violence. Ballistic resistance is a complex function of hardness, toughness, tensile strength, tenacity and yield strength [4]. High impact energy absorption is one of the performances of ballistic resistant materials [5]. So do layered manufacturing of some materials to combine these properties. Rubber is one of the elastic materials that can absorb impact energy. Damage caused by ballistics is one of the causes of the inability to absorb impact energy between the panel and projectile. The coating of elastomers [6] and polyurea [7] on metals can enhance ballistic resistance.

Ballistic impact parameters are complex, such as the relative speed of projectiles and targets, projectile and target shapes, relative stiffness and projectile mass and targets, contact surfaces, geometry and boundary conditions and projectile material characteristics and targets [8] and environmental factors such as speed and direction of wind, if testing is done outdoors. Hence, the resulting failure is very complex. It takes deep observation and analysis and focuses on knowing every difference from the experiment.

Using a physical model in an experiment requires a lot of experimentation that take a long time and is quite costly. Technological advances to avoid the number of experiments are offered using numerical simulations [8, 10].

In the test experiment sometimes no data obtained detail and desired. The numerical simulation of selected models can obtain detailed and comprehensive data and results [11]. The simulation results should be certified by using test experiments to obtain accuracy. A good correlation between the simulation using commercial code and the experimental method was obtained on thin laminate composites with Kevlar 29 reinforcement [8].

2. Literature review and problem statement

Preparation of layered panels, each layer has its own function, the main function of the front layer is to absorb the kinetic energy of the bullet, balancer, deflection and deformation, while the next layer plate serves to absorb the remaining energy of kinetic and shrapnel [12]. The first layer of sanitary composite armor is made with the aim of collecting and breaking the projectile while the next layer and the back-plate function to absorb the remaining kinetic energy from the projectile to stop its speed [13].

The weight and shape of the projectile tip affect the impact of ballistics. The simulation results found that the double layer was able to increase the ballistic resistance of 8.0-25.0 % for the shape of the flat bullet tip, compared with single plates of the same weight. While the impact of projectiles for conical tip projectiles is almost the same on double plates as well as single plates [14]. In contrast to [15] that single plate has superior performance compared to multilayer plate.

The simulation shows that projectile nose shape independently affects minimum ballistic limit [16]. The blunt end of the projectile project increases the ballistic limit on the double plate, but falls when using the ends of the ogival projectile. With the simulations proved, the greater the projectile durability of ballistic resistance increased on the monolithic plate compared to the aluminum-coated plate and the projectile size was more influential than the target configuration variation [17].

Using numerical analysis, the addition of polyuria is capable of absorbing projectile impact energy [7] and contributes positively to the reduction in the residual velocities of projectiles fired on layered composites [18]. The thicker the ceramic layer on the ramp plate , with simulations and ballistic resistance experiments increasing [19]. Ballistic resistance increased with the addition of epoxy adhesive to the ceramics [20]. Polymer composites are used in sandwich form because they are capable of inhibiting projectiles by reducing kinetic energy due to ballistic impact [21].

The process of bullet penetration and evaluation of the energy changes that occur during projectile collisions is done with finite element software. Panels with alumina layer Ti_6Al_4V, UHMPE and as back-plate were varied using Ti_6Al_4V material, carbon fiber plate and aluminum alloy. 60 % projectile energy was transferred to the alumina. Back plate Ti_6Al_4V provides the best resilience compared to carbon fiber plate and aluminum alloy as it improves the energy balance in UHMPE middle layer [22]. The ballistic impact resistance and impact energy absorption of the hybrid composite laminates were enhanced by deposition of micro and nano-fillers into surface of the Kevlar fibers fabrics [23].

Ballistic resistance is affected by material and manufacturing properties. Ballistic resistance of a ballistic resistant material can be observed from damage caused by projectile impacts called ballistic effects. This ballistic impact is influenced by the ability of the material panel to absorb the impact energy. The layered manufacturing produces a different impact with a single plate. Rubber has an elastic material capable of reducing the impact. In this study focused on panel manufacturing independent (non-fix) of black plate. This manufacturing has not been much of a focus on previous research. The effect of layered plate manufacturing is made independent of one other through the addition of rubber to its ballistic capability in terms of energy absorbed by projectile impact.

3. The aim and objectives of the study

The purpose of this study is to determine and analyze the energy absorbed on a single plate and a layered plate with rubber damper due to deformable projectile shot by using finite element numeric simulation.

To accomplish the set goal, the following tasks were set:

– selection of material model and simulation and verification with experimental test result

– analyze the results of the simulation in various variables to determine the influence.

4. Material, methods and numerical model of research

In this study the materials used as test experiments for validation are commercial steel plate (soft plate / back plate), hard plate and commercial rubber. Each of these materials has properties as shown in Table 1. Model of steel plate and projectile using Johnson-Cook strength equation (1) [24], while rubber uses Mooney-Rivlin equation (2) [24–26]. Material data for simulation is shown in Table 2.

Plasticity of metal plat using Johnson Cook Strength equation;

$$\sigma_{eq} = \left(A + B\varepsilon^{N}\right)\left(1 + C\ln\varepsilon^{*}\right)\left(1 - \left(\frac{T - T_0}{T_{melt} - T_0}\right)^{M}\right), \quad (1)$$

with σ_{eq} is equivalent stress (MPa), A is yield stress constant (MPa), B is hardening constant (MPa), ε is equivalent strain, C is strain rate constant, N is hardening exponent, M is thermal softening exponent, ε^{*} is the plastic strain rate and T_{melt}. is the melting temperure of the material (K). While hyperelastic rubber using Mooney-Rivlin equation;

$$\sigma = 2C_1\left[D - \frac{1}{D^3}\right] + 2C_2\left[1 - \frac{1}{D^3}\right], \quad (2)$$

with σ being equivalent stress (MPa), C_1 and C_2 are probability constants (MPa) and D is extension ratio (MPa).

Table 1
The average mechanical properties of materials

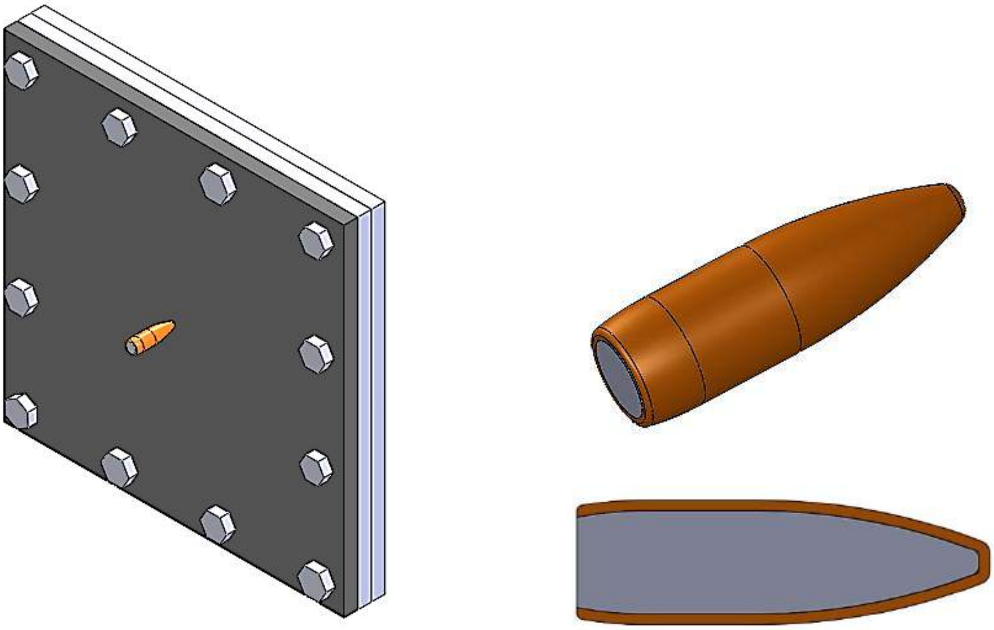
Material	Hardnes	Max Stress (MPa)	ε (%)	Impact Energy (J)	Tear strength (N/mm)	Determination of compressions (%)
Soft	118.21	458.16	31	62.48	–	–

plate/back plate	BHN					
Hard plate	478.23 BHN	1466.19	13	47.77	–	–
Rubber	67 Shore A	4.21	120	–	2.08	34.01

Table 2
Material data for steel plate [27] and data for rubber materials [25]

Data Material	Lead	Brass	Soft Plate	Hard Plate	Rubber
Density *r* (kg/m^3)	10660	8520	8859.782	9112.439	1000
Young's modulus *E* (MPa)	1000	115000	200000	210000	–
Poisson's ratio *n*	0.42	0.31	0.3	0.33	–
Specific heat *Cp* (J/kgK)	124	385	486	452	–
Initial Yield Stress *A* (MPa)	24	206	146.7	819	–
Hardening Constant *B* (MPa)	300	505	896.9	308	–
Hardening Exponent *N*	1	0.42	0.32	0.64	–
Strain Rate Constant *C*	0.1	0.01	0.033	0.0098	–
Thermal Softening Exponent *M*	1	1.68	0.323	1	–
Melting Temperature T_{melt} (K)	760	1189	1773	1800	–
Material constant *C10* (MPa)	–	–	–	–	150
Material constant *C01* (MPa)	–	–	–	–	1.5

The simulation design is shown in Fig. 1 and meshing 0.1 mm is shown in Fig. 2. The speed of the projectile is set at 989 m / s, the time before the start of the collision until the end of the program is 1.5 x 10^{-4} seconds. While the test scheme corresponds to Fig. 3, the research variables are shown in Table 3. The total energy absorbed is obtained by regulating the solution data of total energy received on the panel.



a b

Fig. 1. Design simulation: a – panel target; b – projectile

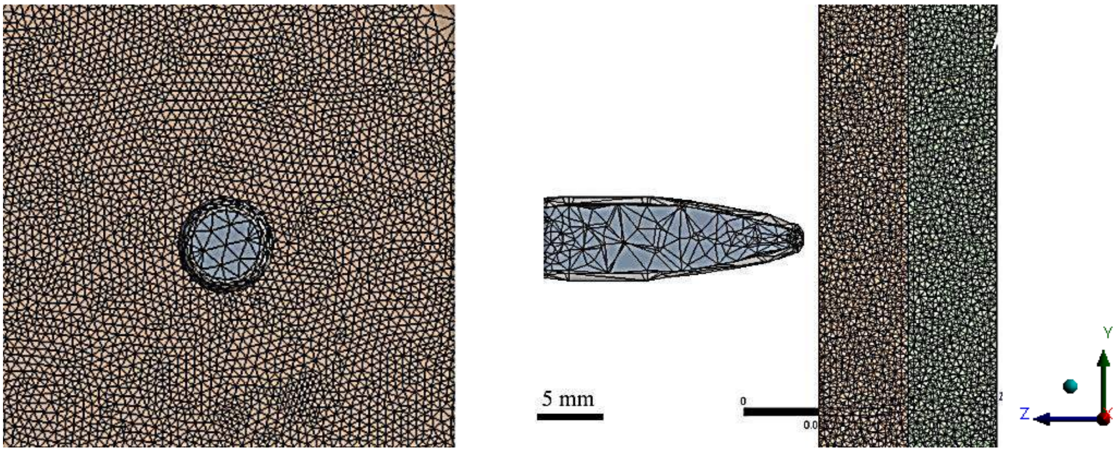


Fig. 2. Meshing concretize

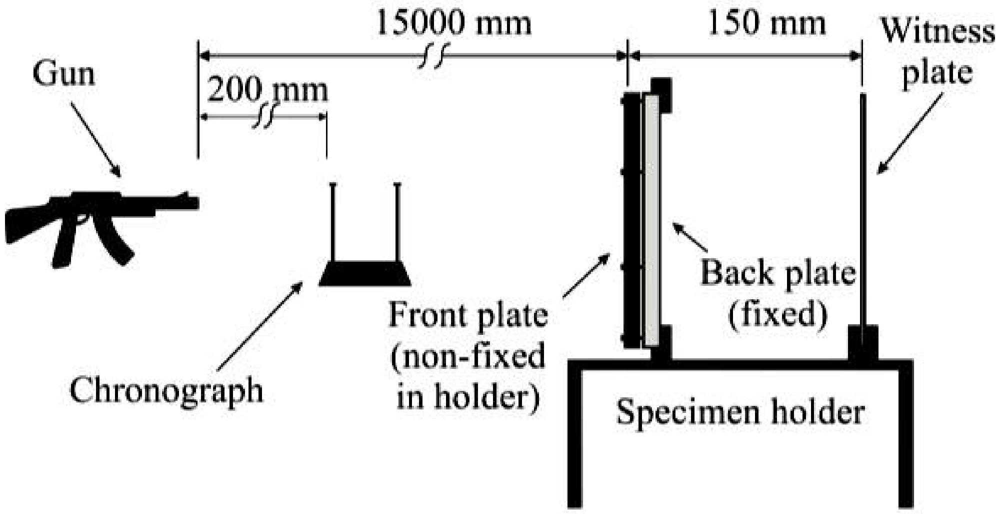
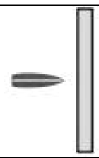
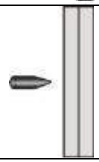
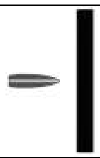


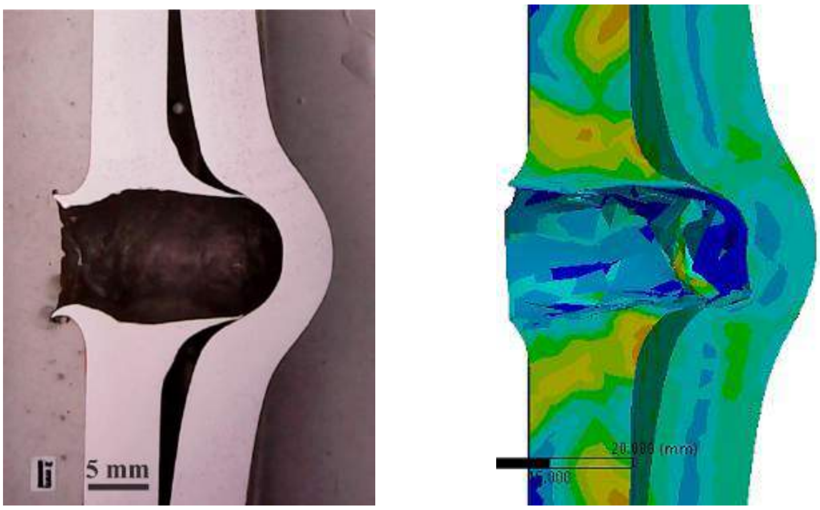
Fig. 3. Experimental testing scheme and conditioning in the simulation

Table 3
Sandwich plate configurations

Configuration	Geometry	Thickness	Code
Soft plate		6 mm soft plate	S
Soft-soft plate		6 mm soft plate - 6 mm back plate	S.0
Soft-rubber-soft plate		6 mm soft plate - 2 mm rubber - 6 mm back plate	S.2
		6 mm soft plate - 4 mm rubber - 6 mm back plate	S.4
		6 mm soft plate - 6 mm rubber - 6 mm back plate	S.6
Hard plate		6 mm hard plate	H
Hard-soft plate		6 mm hard plate - 6 mm back plate	H.0
Hard-rubber-soft plate		6 mm hard plate - 2 mm rubber - 6 mm back plate	H.2
		6 mm hard plate - 4 mm rubber - 6 mm back plate	H.4
		6 mm hard plate - 6 mm rubber - 6 mm back plate	H.6

5. Validation simulation

Multiple test experiments were performed to validate numerical simulations. This is done to see the similarity of ballistic impact on experiment and simulation. The result of experimental and simulated ballistic effects as shown in Fig. 4.



a b

Fig. 4. Ballistic test result: a – experiment; b – simulations

From Fig. 4, measured dimensions of ballistic impact on the experiment and simulation. From the measurement results obtained the level of similarity of ballistic impact is 93 % or with error 7 %.

6. The result of the absorbers energy

The result of numerical simulation is obtained the total energy absorbed at the time of stopping in each configuration. The energy absorbed by each configuration for a given time is 1.5 x 10^{-4} seconds as shown in Fig. 5.

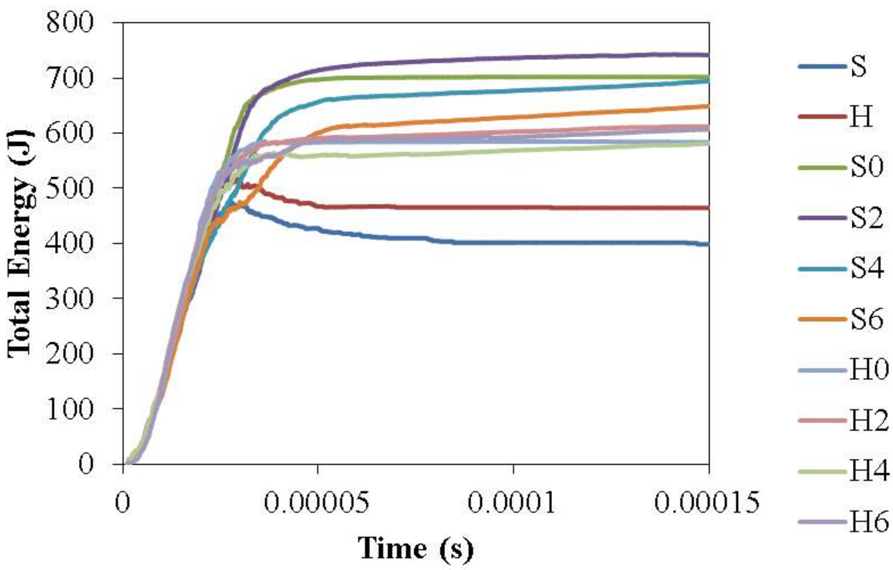


Fig. 5. Total energy versus time

Energy absorbed rises shortly after a collision between projectiles and panels. The process of energy absorption on a single plate increases until the maximum number and decreases in a constant manner. In the S configuration, energy rises significantly until it reaches a maximum of 473.70 J and occurs in 3.10 x 10^{-5} seconds. After achieving the maximum amount of energy absorbed, the energy decrease occurs at 6.38 x 10^{-5} seconds and constantly does to 410.66 J until the simulation is terminated.

Similar to the S configuration, in the H configuration the energy absorption rises significantly to a maximum of 518.53 J and occurs in 2.25 x 10^{-5} seconds. After reaching the maximum energy level it drops to 464.48 J in 5.90 x 10^{-5} seconds and then tends to be constant until the simulation is terminated.

Energy absorption on layered plates tends to be different from single plates. The amount of energy rises significantly shortly after a collision to a certain point and becomes stable until the simulation is terminated. The average energy absorbed in the layered plated plate configuration is faster than the single plate configuration.

The energy absorption capability of each configuration is different. The greatest energy absorbed by each configuration is shown in Fig. 6.

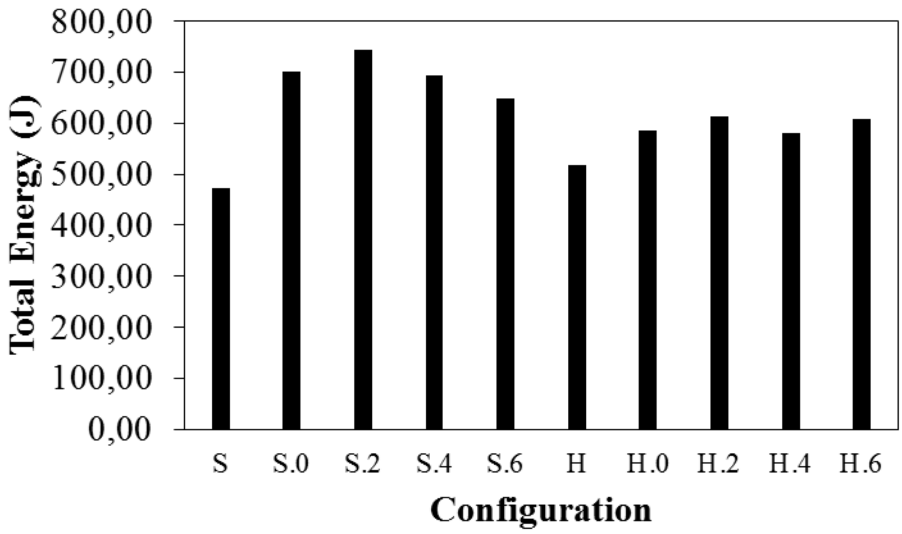
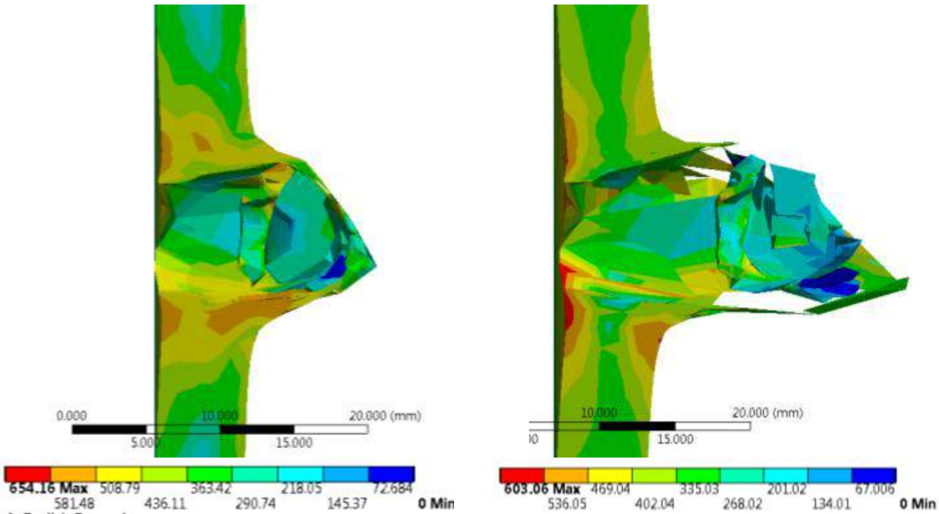


Fig. 6. Total energy versus configuration

The energy absorption on a single plate between soft plate (S) is smaller than the hard plate (H). However, for layered-plate configurations the average high energy absorption occurs on the plate using the soft configuration. The greatest energy occurs in the S2 consolidation on the soft-rubber-soft plate panel with the addition of 2 mm thick rubber. The same is true for the hard configuration plate, where the highest total absorbed energy in the H2 configuration was achieved through adding 2 mm of rubber.

Fig. 7 shows the equivalent stress when the energy reaches the maximum value and the stable value after the maximum in the S configuration. Fig. 8 shows the same conditions in the H-configuration and Fig. 9 shows equivalent stress on the S2 and

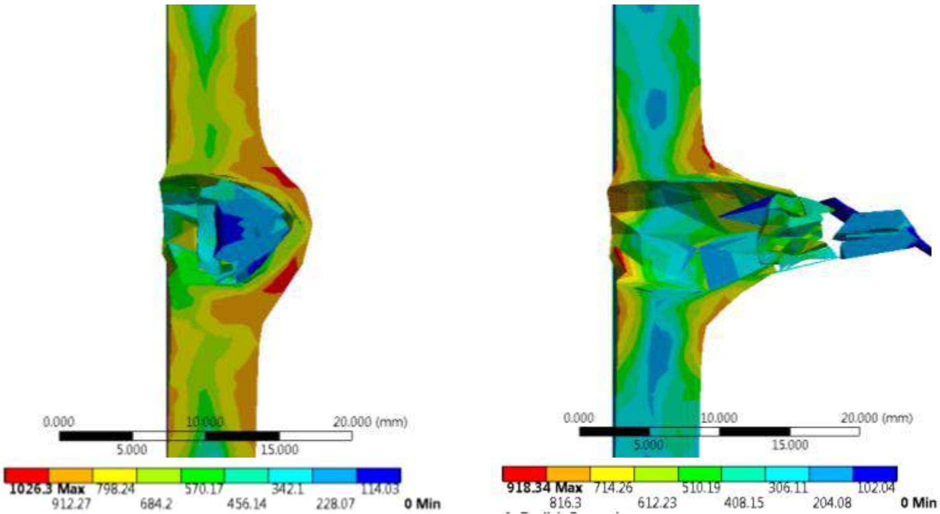
H2 configuration plates. The color of the simulation results shows the distribution of the received voltage of the plate due to the projectile impact force. Red color shows higher concentration of force while blue color shows lower concentration of force.



t = 3.10 x 10^{-5} t = 6.38 x 10^{-5}

a b

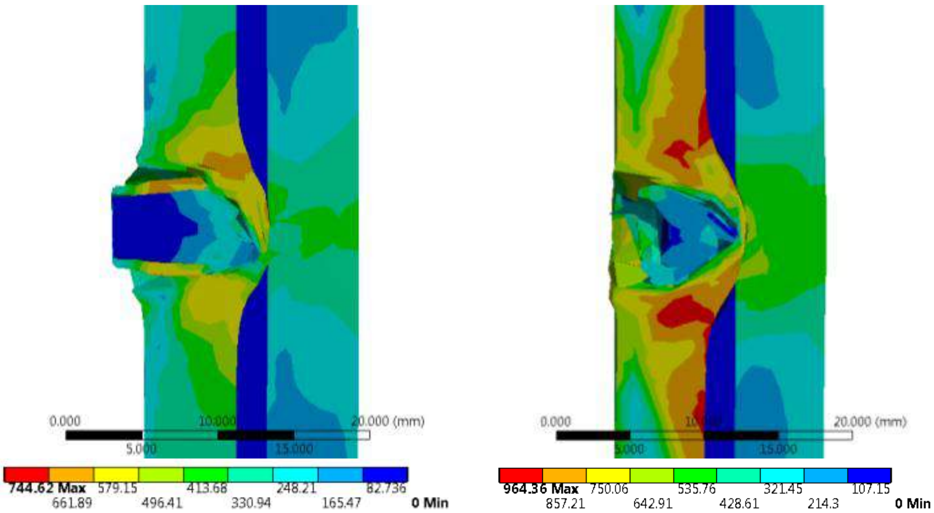
Fig. 7. Equivalent stress on a single configuration plate S: a – when the maximum absorption energy is reached; b – the absorption energy stabilizes



t = 2.25 x 10^{-5} t = 5.90 x 10^{-5}

a b

Fig. 8. Equivalent stress on single configuration plate H: a – when the maximum absorption energy is reached; b – the absorption energy stabilizes



t = 1.80 x 10^{-5} t = 2.40 x 10^{-5}

a b

Fig. 9. Equivalent stress on layered plates when maximum absorption energy is reached: a – S2 configuration; b – H2 configuration

7. Discussion of the absorbers energy

The maximum energy absorption on a single configuration plate S occurs at approximately seconds to 3.1 x 10^{-5}. And after reaching that time the energy absorption decreased. This is because at that moment the projectile has penetrated the plate in a single configuration as shown in Fig. 7 .The impact of a large projectile cannot hold the panel so that the panel reaches its maximum voltage and the panel is pierced after a second to 6.38 x 10^{-5} .After the seconds and the projectiles have passed through the panel, the remaining energy is proved by the tension still visible on the plate (Fig. 7, b).

This is also the case with single H configuration plate. The maximum energy occurs just before the projectile passes through the plate as shown in Fig. 8a. this process occurs at seconds to 2.25 x 10^{-5}. Also visible voltage on the plate reaches the maximum around the impact of the projectile. The energy decreases and is relatively stable after 5.90 x 10^{-5} seconds, this occurs after the projectile passes through the plate as shown in Fig. 8, b.

In contrast to the plated plates, energy rises significantly shortly after the projectiles consume the panel until it reaches a certain number and then tends to be constant. This boundary mark with a perverted projectile will pierce the front plate in a layered configuration. In the S2 configuration panel this condition occurs at 1.80 x 10^{-5} seconds as shown in Fig. 9, a, as seen from the projectile condition will penetrate the front plate.

In H2 configuration, the process occurs similarly to the S2 configuration. Energy rises significantly shortly after the projectile strikes the plate up to a certain value. The limit of increase until it reaches energy that tends to constant occur at seconds to 2.40 x 10^{-5} .This condition occurs when the projectile is capable of piercing the front plate in the H2 configuration as shown in Fig. 9, b.

The larger S2 configuration absorbs the impact energy of the bullet (Fig. 6), this is because the S configuration consists of soft-rubber plates and soft plates. The soft plate energy impeller is larger than the hard plate (Table 1) in the H configuration the addition of rubber thickness increased to 6 mm actually weakens the layered plate structure which causes the total energy to decrease compared to rubber thickness of 2 mm.

The author made an interesting interpretation of the results. This is not a complete section of the discussion. It is necessary to answer these questions:

– what are the shortcomings of the research and what restrictions can be imposed on the use of the results?

– what can be the development of this research and why exactly in this, and also what threats can there be in trying to develop this research in these areas?

8. Conclusion

~~The results of the research can be concluded:~~

1. Experimental and simulation results ballistic impact tests look similar. The level of similarity of ballistic impact is 93 % or with error 7 %.
2. Energy due to the impact ballistic received and absorbed on the panel rises significantly shortly after the collision. On a single plate, this occurs until it reaches a certain number then the energy will decrease because the projectile succeeded in penetrating the plate. While on the layered plate, after the projectile successfully penetrates the front side plate, absorption energy reaches the maximum number and then remains constant until the end of the simulation, which caused the projectile to be unable to penetrate the next plate layer.

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Energy absorbers on the steel plate – rubber laminate after deformable projectile impact

Helmy Purwanto, Rudy Soenoko, Anindito Purnowidodo, Agus Suprapto

Abstract
The sum of the annotation + keywords = should be up to 250 words
In the annotation it is necessary to answer such questions (check yourself):
- What was done?
- Why are you doing this?
- What did you establish as a result of the research?
- Why is this data useful and important?

The ability of energy absorption can be used to measure the strength of material against ballistic impact. This paper aims to analyze the rubber plated energy absorption plate that was shot with deformable projectiles. This study was conducted using numerical simulations based on finite element that have been verified with experimental results. The simulation setting on steel plate with different hardness with the addition of rubber thickness prepared as ballistic test panel. Manufacturing between layers made non fix with back plate. Panel shot by using 5.56x 45 mm deformable caliber bullet with a distance of 15 m of normal attack angle. Finite element code with Johnson-Cook and Mooney-Rivlin elasto-plastic material model was employed to perform the simulation study. Simulation results show the energy due to ballistic impact received and absorbed by the panel rises significantly shortly after the collision until reaching a certain number on a single plate where energy will decrease because the projectile successfully penetrated the plate. While on a layered plate, after the projectile succeeded in penetrating the front side plate, the absorption energy reached the maximum number and then remained constant, which caused the projectile not to be able to penetrate the next layer. These findings indicate that the addition of rubber with a layered structure is able to absorb energy ballistic impact.

Keywords: Energy absorber, hard plate, soft plate, ballistic laminate plate, rubber, ballistic impact, simulation. Keywords in English up to 10 words

We draw your attention that in the text of the article there should be links to all sources of information used, arranged in order, for example, from 1 to 10

1. Introduction

Defense and security play an important role in state sovereignty. One of the most common defense equipment used in the military world is combat vehicles. Combat vehicles are special vehicles equipped with combat equipment and must be able to withstand the opponent's attacks. The success of combat vehicles is in the completion of defense and defense missions [1].

Material on combat vehicles in general is a steel plate. Steel is used because it has characteristics that can be strengthened, easily shaped and can form a structure. Steel is easily made and also has the nature of protection against ballistics. Ballistics is the study of the acceleration of moving objects, in modern ballistics science it is further defined as the study of the force, motion and impact of a projectile fired from a weapon [2]. Projectile clash with the plate resulted in very high strain on the narrow area [3].

Ballistic resistance is not only influenced by target violence. Ballistic resistance is a complex function of hardness, toughness, tensile strength, tenacity and yield strength [4]. High impact energy absorption is one of the performances of ballistic resistant materials [5]. So do layered manufacturing of some materials to combine these properties. Rubber is one of the elastic materials that can absorb impact energy. Damage caused by ballistics is one of the causes of the inability to absorb impact energy between the panel and projectile. The coating of elastomers [6] and polyurea [7] on metals can enhance ballistic resistance.

Ballistic impact parameters are complex, such as the relative speed of projectiles and targets, projectile and target shapes, relative stiffness and projectile mass and targets, contact surfaces, geometry and boundary conditions and projectile material characteristics and targets [8] and environmental factors such as speed and direction of wind, if testing is done outdoors. Hence, the resulting failure is very complex. It takes deep observation and analysis and focuses on knowing every difference from the experiment.

Using a physical model in an experiment requires a lot of experimentation that take a long time and is quite costly. Technological advances to avoid the number of experiments are offered using numerical simulations [8, 10].

In the test experiment sometimes no data obtained detail and desired. The numerical simulation of selected models can obtain detailed and comprehensive data and results [11]. The simulation results should be certified by using test experiments to obtain accuracy. A good correlation between the simulation using commercial code and the experimental method was obtained on thin laminate composites with Kevlar 29 reinforcement [8].

2. Literature review and problem statement

Preparation of layered panels, each layer has its own function, the main function of the front layer is to absorb the kinetic energy of the bullet, balancer, deflection and deformation, while the next layer plate serves to absorb the remaining energy of kinetic and shrapnel [12]. The first layer of sanitary composite armor is made with the aim of collecting and breaking the projectile while the next layer and the back-plate function to absorb the remaining kinetic energy from the projectile to stop its speed [13].

The weight and shape of the projectile tip affect the impact of ballistics. The simulation results found that the double layer was able to increase the ballistic resistance of 8.0-25.0 % for the shape of the flat bullet tip, compared with single plates of the same weight. While the impact of projectiles for conical tip projectiles is almost the same on double plates as well as single plates [14]. In contrast to [15] that single plate has superior performance compared to multilayer plate.

The simulation shows that projectile nose shape independently affects minimum ballistic limit [16]. The blunt end of the projectile project increases the ballistic limit on the double plate, but falls when using the ends of the ogival projectile. With the simulations proved, the greater the projectile durability of ballistic resistance increased on the monolithic plate compared to the aluminum-coated plate and the projectile size was more influential than the target configuration variation [17].

Using numerical analysis, the addition of polyuria is capable of absorbing projectile impact energy [7] and contributes positively to the reduction in the residual velocities of projectiles fired on layered composites [18]. ~~(Mohotti et al., 2013)[6](Mohotti et al. 2013).~~ (the surname is not mentioned in scientific articles, there are enough references to the works) The thicker the ceramic layer on the ramp plate , with simulations and ballistic resistance experiments increasing [19]. Ballistic resistance increased with the addition of epoxy adhesive to the ceramics [20]. Polymer composites are used in sandwich form because they are capable of inhibiting projectiles by reducing kinetic energy due to ballistic impact [21].

The process of bullet penetration and evaluation of the energy changes that occur during projectile collisions is done with finite element software. Panels with alumina layer Ti $_6Al_4V$, UHMPE and as back-plate were varied using Ti_6Al_4V material, carbon fiber plate and aluminum alloy. 60 % projectile energy was transferred to the alumina. Back plate Ti_6Al_4V provides the best resilience compared to carbon fiber plate and aluminum alloy as it improves the energy balance in UHMPE middle layer [22]. The ballistic impact resistance and impact energy absorption of the hybrid composite laminates were enhanced by deposition of micro and nano-fillers into surface of the Kevlar fibers fabrics [23].

Ballistic resistance is affected by material and manufacturing properties. Ballistic resistance of a ballistic resistant material can be observed from damage caused by projectile impacts called ballistic effects. This ballistic impact is influenced by the ability of the material panel to absorb the impact energy. The layered manufacturing produces a different impact with a single plate. Rubber has an elastic material capable of reducing the impact. In this study focused on panel manufacturing independent (non-fix) of black plate. This manufacturing has not been much of a focus on previous research. The effect of layered plate manufacturing is made independent of one other through the addition of rubber to its ballistic capability in terms of energy absorbed by projectile impact.

Section of the article "Analysis of literary data" is intended to show (highlight) unsolved by other scientists part of the problem. The result of the survey is the identification of a "niche" of research not occupied by other scientists in this issue. This section is written on the basis of publications of periodical scientific publications (books, textbooks, monographs to those do not apply). The review of periodicals on the problem investigated by the author should include sources no more than 5-10 years ago, and a review of foreign scientific periodicals on the problem investigated by the author is mandatory.

You can see articles on your topic through keyword search in any database. For example,

1) https://doaj.org/
2) http://www.sciencedirect.com/science/search
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Use 7-10 references to used literature, each of the sources used should be accompanied by a comment (at least one sentence)

3. The aim and objectives of the study

The purpose of this study is to determine and analyze the energy absorbed on a single plate and a layered plate with rubber damper due to deformable projectile shot by using finite element numeric simulation.

~~We completed the following tasks in order to achieve the objective:~~

To accomplish the set goal, the following tasks were set:

- Selection of material model and simulation and verification with experimental test result
- Analyze the results of the simulation in various variables to determine the influence.

4. Material, methods and numerical model of research

In this study the materials used as test experiments for validation are commercial steel plate (soft plate / back plate), hard plate and commercial rubber. Each of these materials has properties as shown in Table 1. Model of steel plate and projectile using Johnson-Cook strength equation (1) [24], while rubber uses Mooney-Rivlin equation (2) [24–26]. Material data for simulation is shown in Table 2.

- The numbering of the formulas must have the form (1), (2), (3)
- Formulas must be typed in the formula editor MathType
- References to the formula in the text have the form (1), (2) - (4)
- Formulas must be numbered
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- The formula is part of the text, therefore, after the formula there should be a semantic sign: if a further sentence goes on, then the point; If there is further clarification, then the comma

Plasticity of metal plat using Johnson Cook Strength equation;

$$\sigma_{eq} = (A + B\,\varepsilon^N)\ \ (1 + C\ln\varepsilon^*)\left(1 - \left(\frac{T - T_0}{T_{melt} - T_0}\right)^M\right), \tag{1}$$

with σ_{eq} is equivalent stress (MPa), A is yield stress constant (MPa), B is hardening constant (MPa), ε is equivalent strain, C is strain rate constant, N is hardening exponent, M is thermal softening exponent, ε^* is the plastic strain rate and T_{melt} is the melting temperature of the material (K). While hyperelastic rubber using Mooney-Rivlin equation;

$$\sigma = 2C_1\left[D - \frac{1}{D^3}\right] + 2C_2\left[1 - \frac{1}{D^3}\right], \quad (2)$$

with σ being equivalent stress (MPa), C_1 and C_2 are probability constants (MPa) and D is extension ratio (MPa).

Table 1

The average mechanical properties of materials

Material	Hardnes	Max Stress (MPa)	ε (%)	Impact Energy (J)	Tear strength (N/mm)	Determination of compressions (%)
Soft plate/back plate	118.21 BHN	458.16	31	62.48	-	-
Hard plate	478.23 BHN	1466.19	13	47.77	-	-
Rubber	67 Shore A	4.21	120	-	2.08	34.01

Table 2

Material data for steel plate [27] and data for rubber materials [25]

Data Material	Lead	Brass	Soft Plate	Hard Plate	Rubber
Density *r* (kg/m^3)	10660	8520	8859.782	9112.439	1000
Young's modulus *E* (MPa)	1000	115000	200000	210000	-
Poisson's ratio *n*	0.42	0.31	0.3	0.33	-
Specific heat *Cp* (J/kgK)	124	385	486	452	-
Initial Yield Stress *A* (MPa)	24	206	146.7	819	-
Hardening Constant *B* (MPa)	300	505	896.9	308	-
Hardening Exponent *N*	1	0.42	0.32	0.64	-
Strain Rate Constant *C*	0.1	0.01	0.033	0.0098	-
Thermal Softening Exponent *M*	1	1.68	0.323	1	-
Melting Temperature T_{melt} (K)	760	1189	1773	1800	-
Material constant *C10* (MPa)	-	-	-	-	150
Material constant *C01* (MPa)	-	-	-	-	1.5

The simulation design is shown in Fig. 1 and meshing 0.1 mm is shown in Fig. 2. The speed of the projectile is set at 989 m / s, the time before the start of the collision until the end of the program is 1.5 x 10^{-4} seconds. While the test scheme corresponds to Fig. 3, the research variables are shown in Table 3. The total energy absorbed is obtained by regulating the solution data of total energy received on the panel.

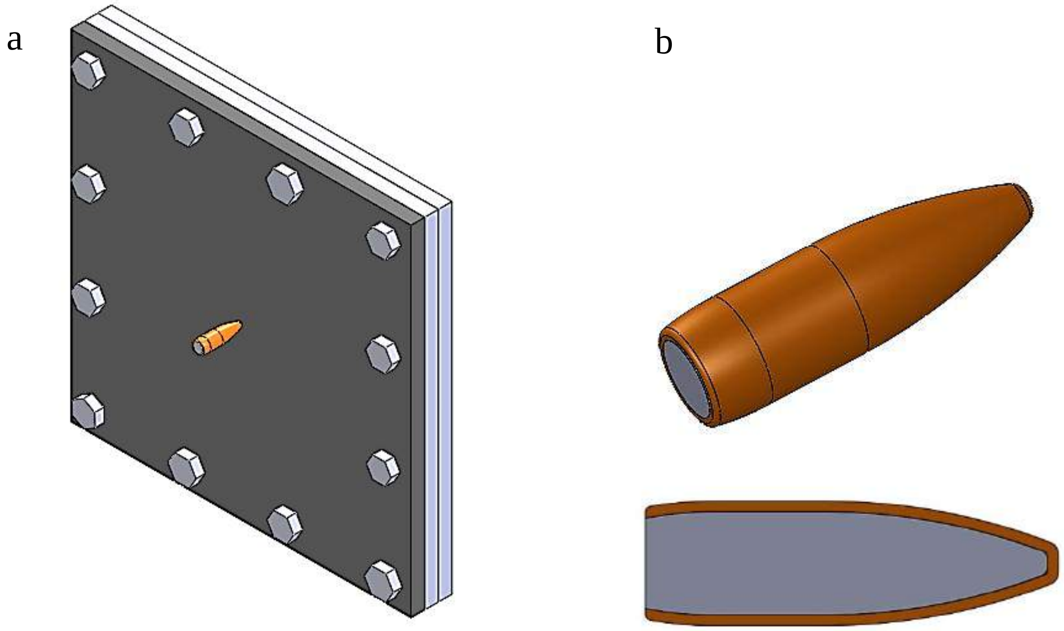

Fig. 1. Design simulation: a – panel target; b – projectile.
Fig. 1. The main signature: a - .....; b - ....

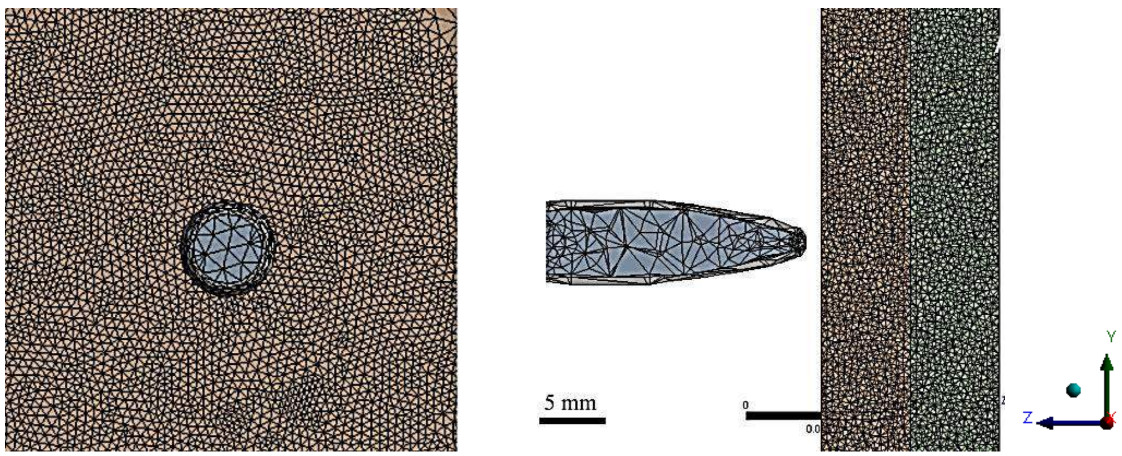

Fig. 2. Meshing concretize

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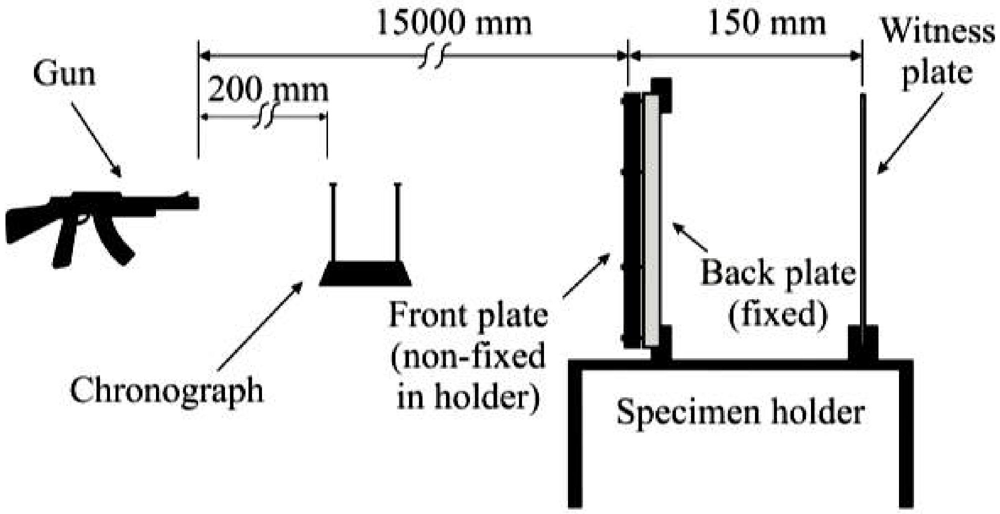
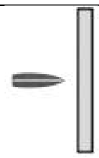
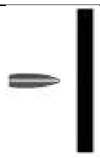


Fig. 3. Experimental testing scheme and conditioning in the simulation

Table 3
Sandwich plate configurations

Configuration	Geometry	Thickness	Code
Soft plate		6 mm soft plate	S
Soft-soft plate		6 mm soft plate - 6 mm back plate	S.0
Soft-rubber-soft plate		6 mm soft plate - 2 mm rubber - 6 mm back plate	S.2
		6 mm soft plate - 4 mm rubber - 6 mm back plate	S.4
		6 mm soft plate - 6 mm rubber - 6 mm back plate	S.6
Hard plate		6 mm hard plate	H
Hard-soft plate		6 mm hard plate - 6 mm back plate	H.0
Hard-rubber-soft plate		6 mm hard plate - 2 mm rubber - 6 mm back plate	H.2
		6 mm hard plate - 4 mm rubber - 6 mm back plate	H.4
		6 mm hard plate - 6 mm rubber - 6 mm back plate	H.6

5. Validation simulation

Multiple test experiments were performed to validate numerical simulations. This is done to see the similarity of ballistic impact on experiment and simulation. The result of experimental and simulated ballistic effects as shown in Fig. 4.

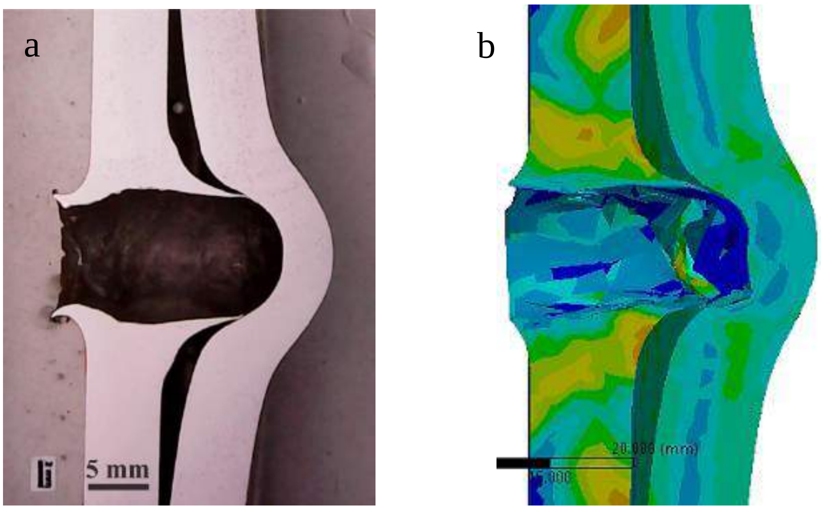


Fig. 4. Ballistic test result: a – experiment; b - simulations

From Fig. 4, measured dimensions of ballistic impact on the experiment and simulation. From the measurement results obtained the level of similarity of ballistic impact is 93 % or with error 7 %.

6. The result of the absorbers energy

The result of numerical simulation is obtained the total energy absorbed at the time of stopping in each configuration. The energy absorbed by each configuration for a given time is 1.5 x 10^{-4} seconds as shown in Fig. 5.

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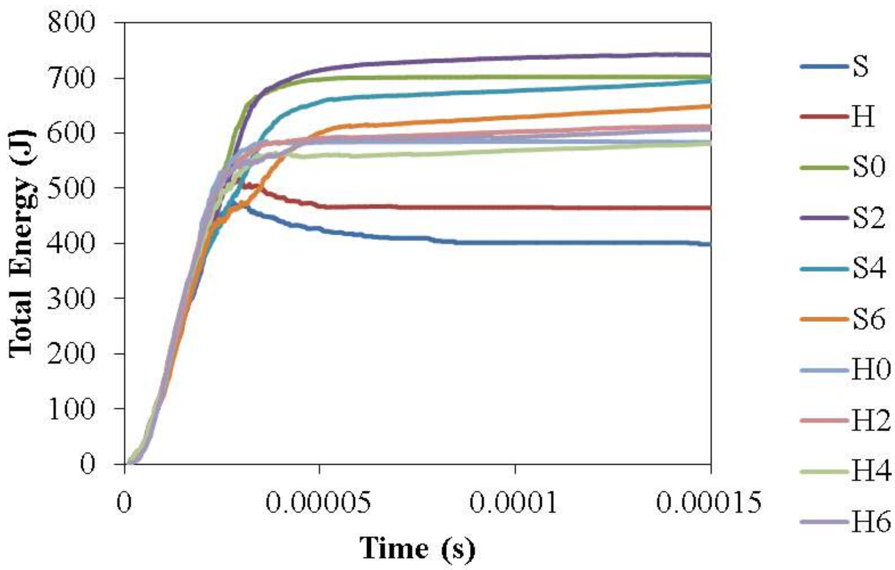

Fig. 5. Total energy versus time

Energy absorbed rises shortly after a collision between projectiles and panels. The process of energy absorption on a single plate increases until the maximum number and decreases in a constant manner. In the S configuration, energy rises significantly until it reaches a maximum of 473.70 J and occurs in 3.10 x 10^{-5} seconds. After achieving the maximum amount of energy absorbed, the energy decrease occurs at 6.38 x 10^{-5} seconds and constantly does to 410.66 J until the simulation is terminated.

Similar to the S configuration, in the H configuration the energy absorption rises significantly to a maximum of 518.53 J and occurs in 2.25 x 10^{-5} seconds. After reaching the maximum energy level it drops to 464.48 J in 5.90 x 10^{-5} seconds and then tends to be constant until the simulation is terminated.

Energy absorption on layered plates tends to be different from single plates. The amount of energy rises significantly shortly after a collision to a certain point and becomes stable until the simulation is terminated. The average energy absorbed in the layered plated plate configuration is faster than the single plate configuration.

The energy absorption capability of each configuration is different. The greatest energy absorbed by each configuration is shown in Fig. 6.

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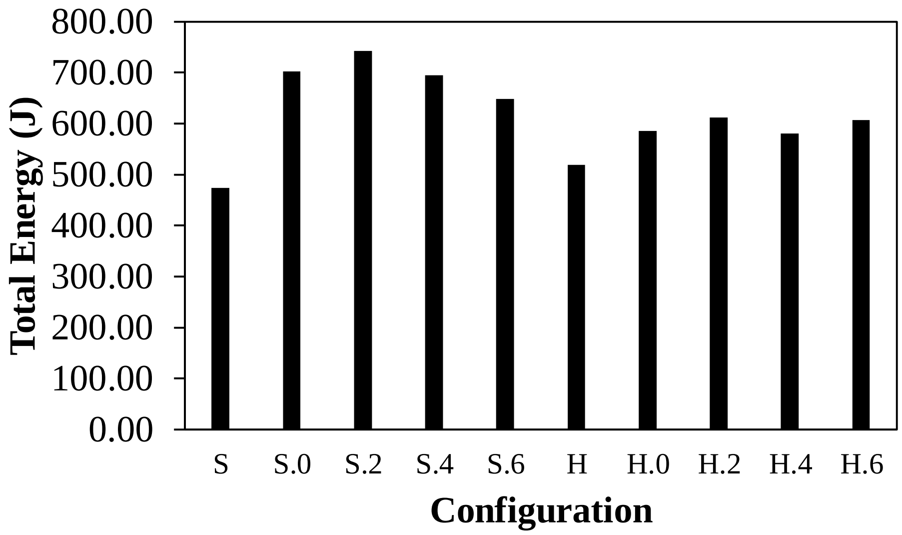
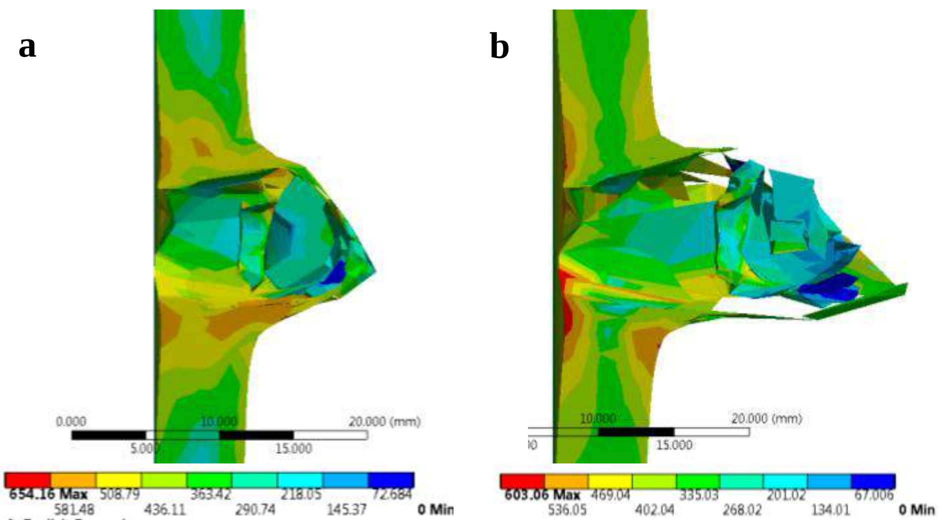


Fig. 6. Total energy versus configuration

The energy absorption on a single plate between soft plate (S) is smaller than the hard plate (H). However, for layered-plate configurations the average high energy absorption occurs on the plate using the soft configuration. The greatest energy occurs in the S2 consolidation on the soft-rubber-soft plate panel with the addition of 2 mm thick rubber. The same is true for the hard configuration plate, where the highest total absorbed energy in the H2 configuration was achieved through adding 2 mm of rubber.

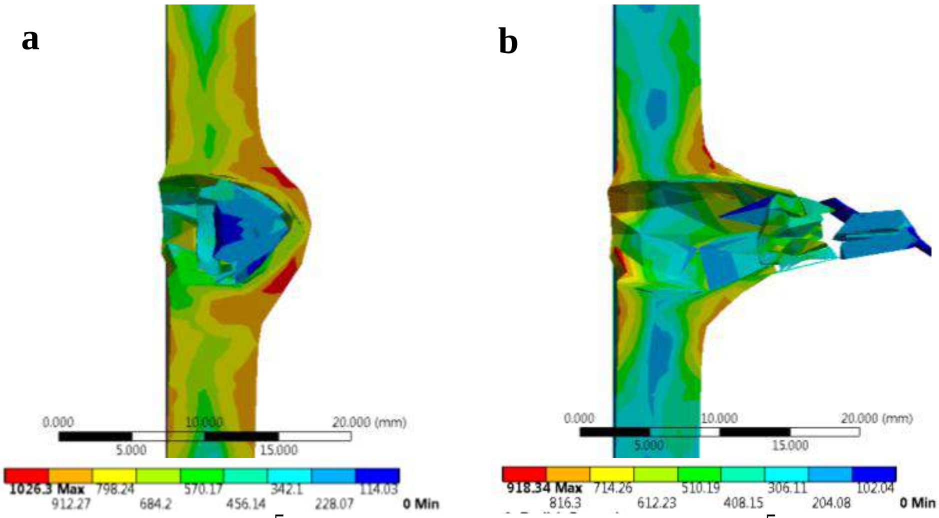
Fig. 7 shows the equivalent stress when the energy reaches the maximum value and the stable value after the maximum in the S configuration. Fig. 8 shows the same conditions in the H-configuration and Fig. 9 shows equivalent stress on the S2 and H2 configuration plates. The color of the simulation results shows the distribution of the received voltage of the plate due to the projectile impact force. Red color shows higher concentration of force while blue color shows lower concentration of force.



t = 3.10 x 10^{-5} t = 6.38 x 10^{-5}

Fig. 7. Equivalent stress on a single configuration plate S: a - when the maximum absorption energy is reached; b - the absorption energy stabilizes

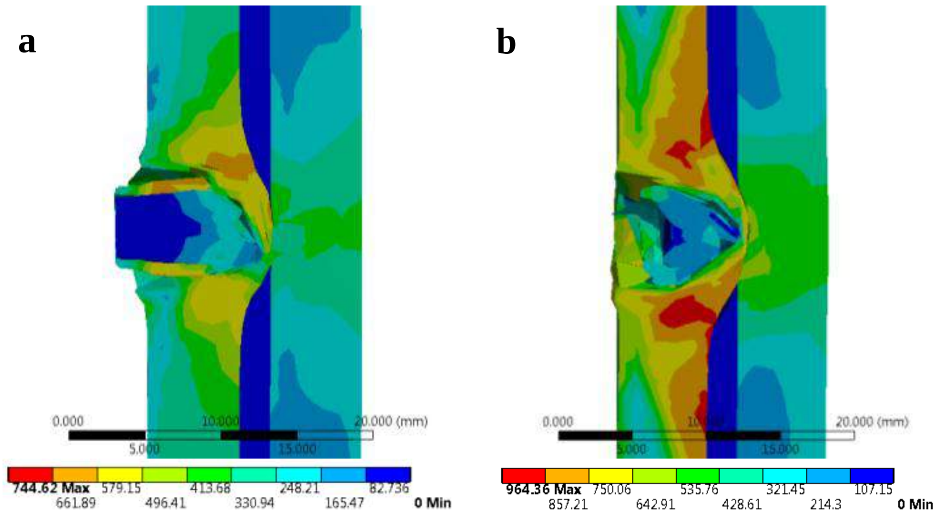
Fig. 7. The main signature: a - .....; b - ....



t = 2.25 x 10^{-5} t = 5.90 x 10^{-5}

Fig. 8. Equivalent stress on single configuration plate H: a - when the maximum absorption energy is reached; b - the absorption energy stabilizes

Fig. 8. The main signature: a - .....; b - ....



t = 1.80 x 10^{-5} t = 2.40 x 10^{-5}

Fig. 9. Equivalent stress on layered plates when maximum absorption energy is reached: a - S2 configuration; b - H2 configuration

Fig. 9. The main signature: a - .....; b - ....

7. Discussion of the absorbers energy

The maximum energy absorption on a single configuration plate S occurs at approximately seconds to 3.1 x 10^{-5}. And after reaching that time the energy absorption decreased. This is because at that moment the projectile has penetrated the plate in a single configuration as shown in Fig. 7 .The impact of a large projectile cannot hold the panel so that the panel reaches its maximum voltage and the panel is pierced after a second to 6.38 x 10^{-5} .After the seconds and the projectiles have passed through the panel, the remaining energy is proved by the tension still visible on the plate (Fig. 7, b).

This is also the case with single H configuration plate. The maximum energy occurs just before the projectile passes through the plate as shown in Fig. 8a. this process occurs at seconds to 2.25 x 10^{-5}. Also visible voltage on the plate reaches the maximum around the impact of the projectile. The energy decreases and is relatively stable after 5.90 x 10^{-5} seconds, this occurs after the projectile passes through the plate as shown in Fig. 8, b.

In contrast to the plated plates, energy rises significantly shortly after the projectiles consume the panel until it reaches a certain number and then tends to be constant. This boundary mark with a perverted projectile will pierce the front plate in a layered configuration. In the S2 configuration panel this condition occurs at 1.80 x 10^{-5} seconds as shown in Fig. 9, a, as seen from the projectile condition will penetrate the front plate.

In H2 configuration, the process occurs similarly to the S2 configuration. Energy rises significantly shortly after the projectile strikes the plate up to a certain value. The limit of increase until it reaches energy that tends to constant occur at seconds to 2.40 x 10^{-5} .This condition occurs when the projectile is capable of piercing the front plate in the H2 configuration as shown in Fig. 9, b.

The larger S2 configuration absorbs the impact energy of the bullet (Fig. 6), this is because the S configuration consists of soft-rubber plates and soft plates. The soft plate energy impeller is larger than the hard plate (Table 1) in the H configuration the addition of rubber thickness increased to 6 mm actually weakens the layered plate structure which causes the total energy to decrease compared to rubber thickness of 2 mm.

8. Conclusion

In this section, describe the conclusions in the conclusions of the tasks that you set yourself in Section 3, but do not repeat the tasks themselves verbatim - this should be a description of the solutions to problems

As a result of the research:

1. ... indicating the qualitative or quantitative indicators of the results of the study

2. ... indicating the qualitative or quantitative indicators of the results of the study

3. ... indicating the qualitative or quantitative indicators of the results of the study

The results of the research can be concluded:

1. Experimental and simulation results ballistic impact tests look similar. The level of similarity of ballistic impact is 93 % or with error 7 %.
2. Energy due to the impact ballistic received and absorbed on the panel rises significantly shortly after the collision. On a single plate, this occurs until it reaches a certain number then the energy will decrease because the projectile succeeded in penetrating the plate. While on the layered plate, after the projectile successfully penetrates the front side plate, absorption energy reaches the maximum number and then remains constant until the end of the

simulation, which caused the projectile to be unable to penetrate the next plate layer.

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UDC 621

ENERGY ABSORBERS ON THE STEEL PLATE – RUBBER LAMINATE AFTER DEFORMABLE PROJECTILE IMPACT

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The ability of energy absorption can be used to measure the strength of material against ballistic impact. This paper aims to analyze the rubber plated energy absorption plate that was shot with deformable projectiles. This study was conducted using numerical simulations based on finite element that have been verified with experimental results. The simulation setting on steel plate with different hardness with the addition of rubber thickness prepared as ballistic test panel. Manufacturing between layers made non fix with back plate. Panel shot by using 5.56x 45 mm deformable caliber bullet with a distance of 15 m of normal attack angle. Finite element code with Johnson-Cook and Mooney-Rivlin elasto-plastic material model was employed to perform the simulation study. Simulation results show the energy due to ballistic impact received and absorbed by the panel rises significantly shortly after the collision until reaching a certain number on a single plate where energy will decrease because the projectile successfully penetrated the plate. While on a layered plate, after the projectile succeeded in penetrating the front side plate, the absorption energy reached the maximum number and then remained constant, which caused the projectile not to be able to penetrate the next layer. These findings indicate that the addition of rubber with a layered structure is able to absorb energy ballistic impact

Keywords: Energy absorber, hard plate, soft plate, ballistic laminate plate, rubber, ballistic impact, simulation

1. Introduction

Defense and security play an important role in state sovereignty. One of the most common defense equipment used in the military world is combat vehicles. Combat vehicles are special vehicles equipped with combat equipment and must be able to withstand the opponent's attacks. The success of combat vehicles is in the completion of defense and defense missions [1].

Material on combat vehicles in general is a steel plate. Steel is used because it has characteristics that can be strengthened, easily shaped and can form a structure.

Steel is easily made and also has the nature of protection against ballistics. Ballistics is the study of the acceleration of moving objects, in modern ballistics science it is further defined as the study of the force, motion and impact of a projectile fired from a weapon [2]. Projectile clash with the plate resulted in very high strain on the narrow area [3].

Ballistic resistance is not only influenced by target violence. Ballistic resistance is a complex function of hardness, toughness, tensile strength, tenacity and yield strength [4]. High impact energy absorption is one of the performances of ballistic resistant materials [5]. So do layered manufacturing of some materials to combine these properties. Rubber is one of the elastic materials that can absorb impact energy. Damage caused by ballistics is one of the causes of the inability to absorb impact energy between the panel and projectile. The coating of elastomers [6] and polyurea [7] on metals can enhance ballistic resistance.

Ballistic impact parameters are complex, such as the relative speed of projectiles and targets, projectile and target shapes, relative stiffness and projectile mass and targets, contact surfaces, geometry and boundary conditions and projectile material characteristics and targets [8] and environmental factors such as speed and direction of wind, if testing is done outdoors. Hence, the resulting failure is very complex. It takes deep observation and analysis and focuses on knowing every difference from the experiment.

Using a physical model in an experiment requires a lot of experimentation that take a long time and is quite costly. Technological advances to avoid the number of experiments are offered using numerical simulations [8, 10].

In the test experiment sometimes no data obtained detail and desired. The numerical simulation of selected models can obtain detailed and comprehensive data and results [11]. The simulation results should be certified by using test experiments to obtain accuracy. A good correlation between the simulation using commercial code and the experimental method was obtained on thin laminate composites with Kevlar 29 reinforcement [8].

2. Literature review and problem statement

Preparation of layered panels, each layer has its own function, the main function of the front layer is to absorb the kinetic energy of the bullet, balancer, deflection and deformation, while the next layer plate serves to absorb the remaining energy of kinetic and shrapnel [12]. The first layer of sanitary composite armor is made with the aim of collecting and breaking the projectile while the next layer and the back-plate function to absorb the remaining kinetic energy from the projectile to stop its speed [13].

The weight and shape of the projectile tip affect the impact of ballistics. The simulation results found that the double layer was able to increase the ballistic resistance of 8.0–25.0 % for the shape of the flat bullet tip, compared with single plates of the same weight. While the impact of projectiles for conical tip projectiles is almost the same on double plates as well as single plates [14]. In contrast to [15] that single plate has superior performance compared to multilayer plate.

The simulation shows that projectile nose shape independently affects minimum ballistic limit [16]. The blunt end of the projectile project increases the ballistic limit on the double plate, but falls when using the ends of the ogival projectile. With the simulations proved, the greater the projectile durability of ballistic resistance increased on the monolithic plate compared to the aluminum-coated plate and the projectile size was more influential than the target configuration variation [17].

Using numerical analysis, the addition of polyuria is capable of absorbing projectile impact energy [7] and contributes positively to the reduction in the residual velocities of projectiles fired on layered composites [18]. The thicker the ceramic layer on the ramp plate , with simulations and ballistic resistance experiments increasing [19]. Ballistic resistance increased with the addition of epoxy adhesive to the ceramics [20]. Polymer composites are used in sandwich form because they are capable of inhibiting projectiles by reducing kinetic energy due to ballistic impact [21].

The process of bullet penetration and evaluation of the energy changes that occur during projectile collisions is done with finite element software. Panels with alumina layer Ti $_6Al_4V$, UHMPE and as back-plate were varied using Ti_6Al_4V material, carbon fiber plate and aluminum alloy. 60 % projectile energy was transferred to the alumina. Back plate Ti_6Al_4V provides the best resilience compared to carbon fiber plate and aluminum alloy as it improves the energy balance in UHMPE middle layer [22]. The ballistic impact resistance and impact energy absorption of the hybrid composite laminates were enhanced by deposition of micro and nano-fillers into surface of the Kevlar fibers fabrics [23].

Ballistic resistance is affected by material and manufacturing properties. Ballistic resistance of a ballistic resistant material can be observed from damage caused by projectile impacts called ballistic effects. This ballistic impact is influenced by the ability of the material panel to absorb the impact energy. The layered manufacturing produces a different impact with a single plate. Rubber has an elastic material capable of reducing the impact. In this study focused on panel manufacturing independent (non-fix) of black plate. This manufacturing has not been much of a focus on previous research. The effect of layered plate manufacturing is made independent of one other through the addition of rubber to its ballistic capability in terms of energy absorbed by projectile impact.

3. The aim and objectives of the study

The purpose of this study is to determine and analyze the energy absorbed on a single plate and a layered plate with rubber damper due to deformable projectile shot by using finite element numeric simulation.

To accomplish the set goal, the following tasks were set:

– selection of material model and simulation and verification with experimental test result;

– analyze the results of the simulation in various variables to determine the influence.

4. Material, methods and numerical model of research

In this study the materials used as test experiments for validation are commercial steel plate (soft plate/back plate), hard plate and commercial rubber. Each of these materials has properties as shown in Table 1. Model of steel plate and projectile using Johnson-Cook strength equation (1) [24], while rubber uses Mooney-Rivlin equation (2) [24–26]. Material data for simulation is shown in Table 2.

Plasticity of metal plat using Johnson Cook Strength equation;

$$\sigma_{eq} = \left(A + B\varepsilon^{N}\right)\left(1 + C\ln\varepsilon^{*}\right)\left(1 - \left(\frac{T - T_0}{T_{melt} - T_0}\right)^{M}\right), \qquad (1)$$

with σ_{eq} is equivalent stress (MPa), A is yield stress constant (MPa), B is hardening constant (MPa), ε is equivalent strain, C is strain rate constant, N is hardening exponent, M is thermal softening exponent, ε^{*} is the plastic strain rate and T_{melt}. is the melting temperure of the material (K). While hyperelastic rubber using Mooney-Rivlin equation;

$$\sigma = 2C_1\left[D - \frac{1}{D^3}\right] + 2C_2\left[1 - \frac{1}{D^3}\right], \qquad (2)$$

with σ being equivalent stress (MPa), C_1 and C_2 are probability constants (MPa) and D is extension ratio (MPa).

Table 1
The average mechanical properties of materials

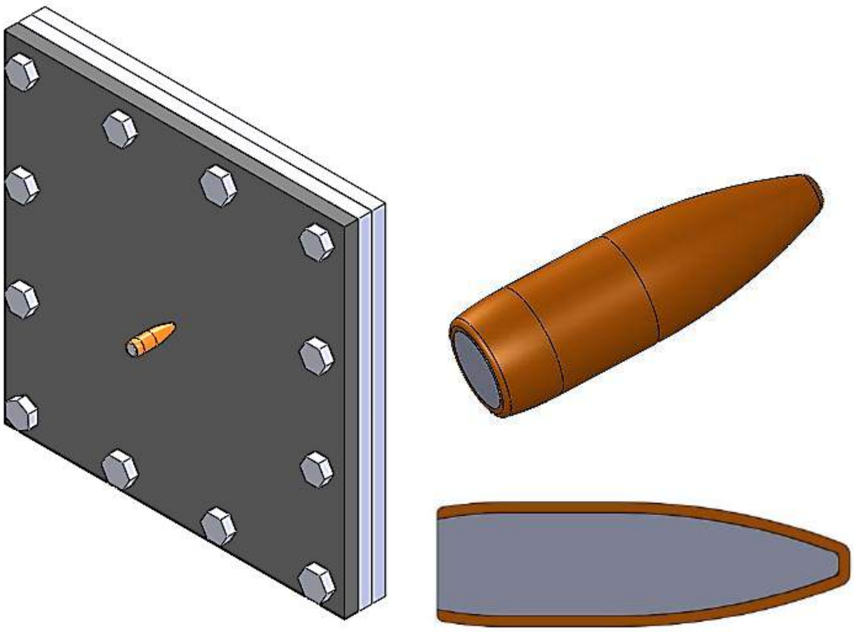
Material	Hardnes	Max Stress (MPa)	ε (%)	Impact Energy (J)	Tear strength (N/mm)	Determination of compressions (%)
Soft plate/back plate	118.21 BHN	458.16	31	62.48	–	–
Hard plate	478.23 BHN	1466.19	13	47.77	–	–
Rubber	67 Shore A	4.21	120	–	2.08	34.01

Table 2
Material data for steel plate [27] and data for rubber materials [25]

Data Material	Lead	Brass	Soft Plate	Hard Plate	Rubber
Density *r* (kg/m^3)	10660	8520	8859.782	9112.439	1000
Young's modulus *E* (MPa)	1000	115000	200000	210000	–
Poisson's ratio *n*	0.42	0.31	0.3	0.33	–
Specific heat *Cp* (J/kgK)	124	385	486	452	–

Initial Yield Stress *A* (MPa)	24	206	146.7	819	–
Hardening Constant *B* (MPa)	300	505	896.9	308	–
Hardening Exponent *N*	1	0.42	0.32	0.64	–
Strain Rate Constant *C*	0.1	0.01	0.033	0.0098	–
Thermal Softening Exponent *M*	1	1.68	0.323	1	–
Melting Temperature T_{melt} (K)	760	1189	1773	1800	–
Material constant *C*10 (MPa)	–	–	–	–	150
Material constant *C*01 (MPa)	–	–	–	–	1.5

The simulation design is shown in Fig. 1 and meshing 0.1 mm is shown in Fig. 2. The speed of the projectile is set at 989 m/s, the time before the start of the collision until the end of the program is 1.5×10^{-4} seconds. While the test scheme corresponds to Fig. 3, the research variables are shown in Table 3. The total energy absorbed is obtained by regulating the solution data of total energy received on the panel.



a b

Fig. 1. Design simulation: *a* – panel target; *b* – projectile

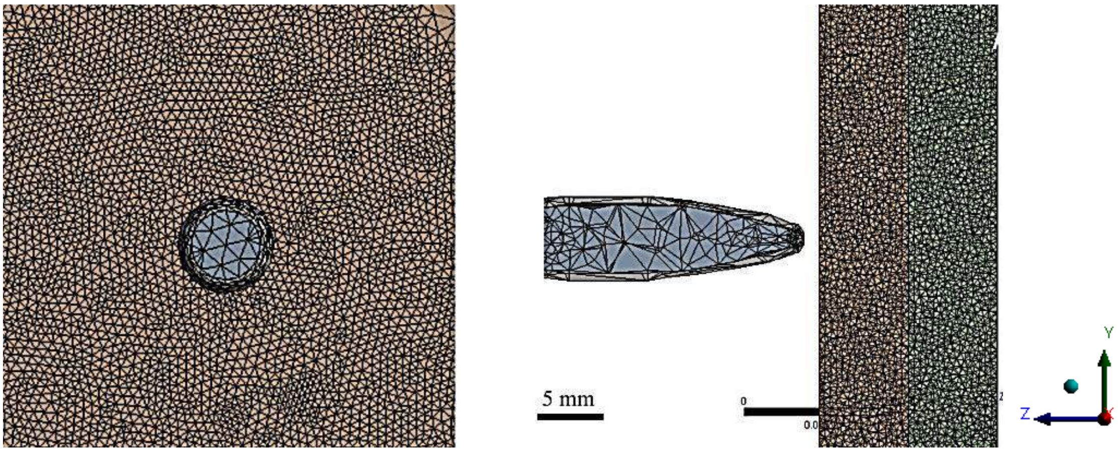


Fig. 2. Meshing concretize

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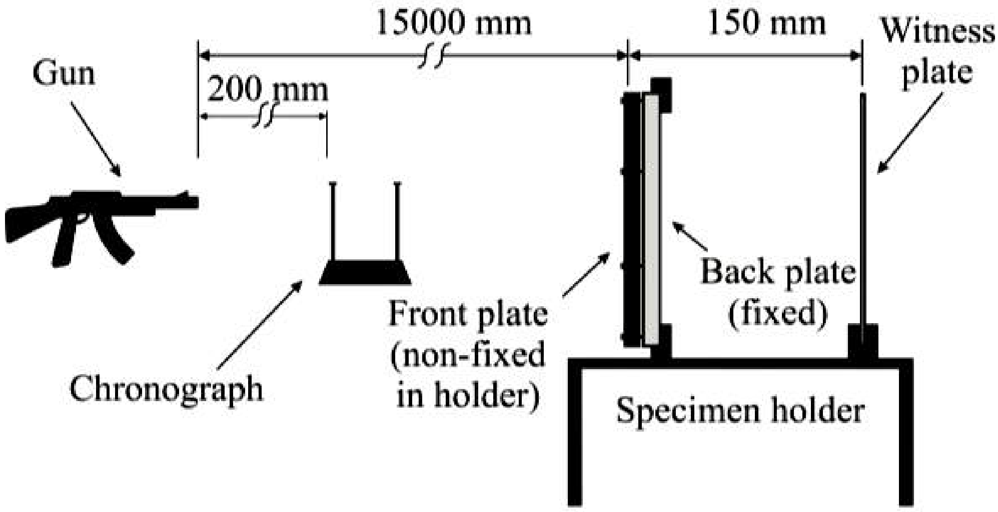

Fig. 3. Experimental testing scheme and conditioning in the simulation

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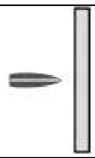
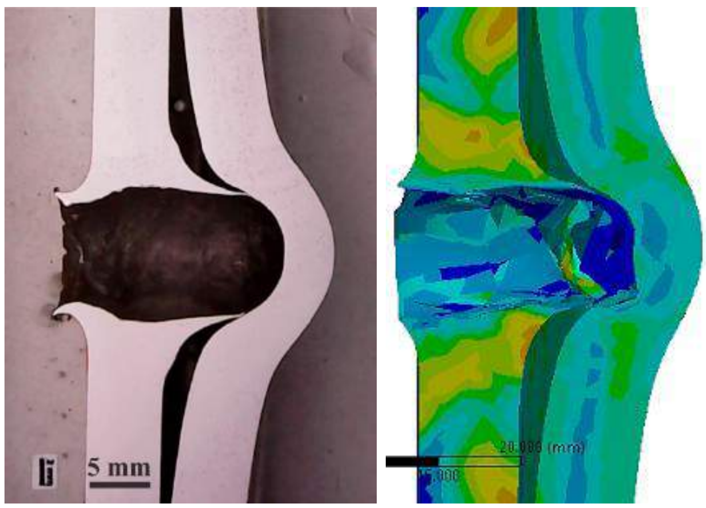
Table 3
Sandwich plate configurations

Configuration	Geometry	Thickness	Code
Soft plate		6 mm soft plate	S
Soft-soft plate		6 mm soft plate – 6 mm back plate	S.0
Soft-rubber-soft plate		6 mm soft plate – 2 mm rubber – 6 mm back plate	S.2
		6 mm soft plate – 4 mm rubber – 6 mm back plate	S.4

		6 mm soft plate – 6 mm rubber – 6 mm back plate	S.6
Hard plate		6 mm hard plate	H
Hard-soft plate		6 mm hard plate – 6 mm back plate	H.0
Hard-rubber-soft plate		6 mm hard plate – 2 mm rubber – 6 mm back plate	H.2
		6 mm hard plate – 4 mm rubber – 6 mm back plate	H.4
		6 mm hard plate – 6 mm rubber – 6 mm back plate	H.6

5. Validation simulation

Multiple test experiments were performed to validate numerical simulations. This is done to see the similarity of ballistic impact on experiment and simulation. The result of experimental and simulated ballistic effects as shown in Fig. 4.



a b

Fig. 4. Ballistic test result: *a* – experiment; *b* – simulations

From Fig. 4, measured dimensions of ballistic impact on the experiment and simulation. From the measurement results obtained the level of similarity of ballistic impact is 93 % or with error 7 %.

6. The result of the absorbers energy

The result of numerical simulation is obtained the total energy absorbed at the time of stopping in each configuration. The energy absorbed by each configuration for a given time is 1.5 x 10^{-4} seconds as shown in Fig. 5.

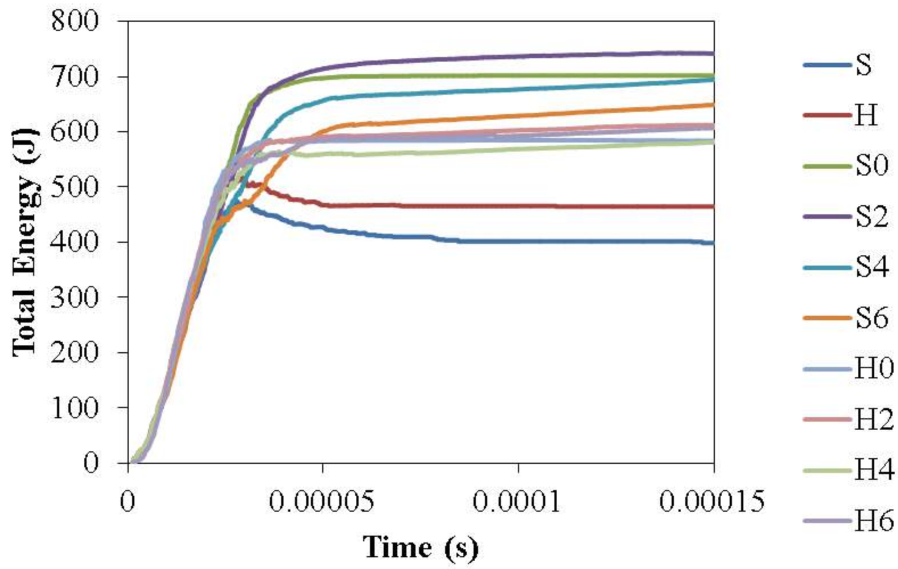


Fig. 5. Total energy versus time

Energy absorbed rises shortly after a collision between projectiles and panels. The process of energy absorption on a single plate increases until the maximum number and decreases in a constant manner. In the S configuration, energy rises significantly until it reaches a maximum of 473.70 J and occurs in 3.10 x 10^{-5} seconds. After achieving the maximum amount of energy absorbed, the energy decrease occurs at 6.38×10^{-5} seconds and constantly does to 410.66 J until the simulation is terminated.

Similar to the S configuration, in the H configuration the energy absorption rises significantly to a maximum of 518.53 J and occurs in 2.25×10^{-5} seconds. After reaching the maximum energy level it drops to 464.48 J in 5.90×10^{-5} seconds and then tends to be constant until the simulation is terminated.

Energy absorption on layered plates tends to be different from single plates. The amount of energy rises significantly shortly after a collision to a certain point and becomes stable until the simulation is terminated. The average energy absorbed in the layered plated plate configuration is faster than the single plate configuration.

The energy absorption capability of each configuration is different. The greatest energy absorbed by each configuration is shown in Fig. 6.

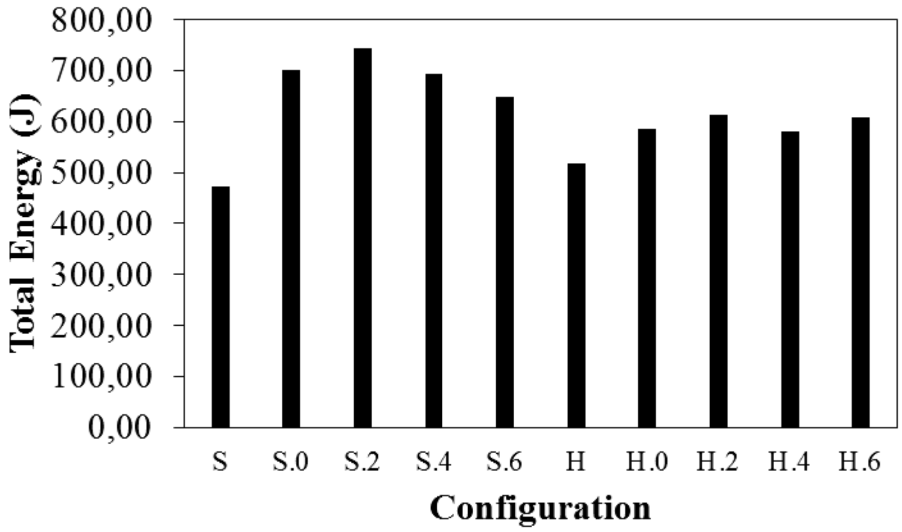
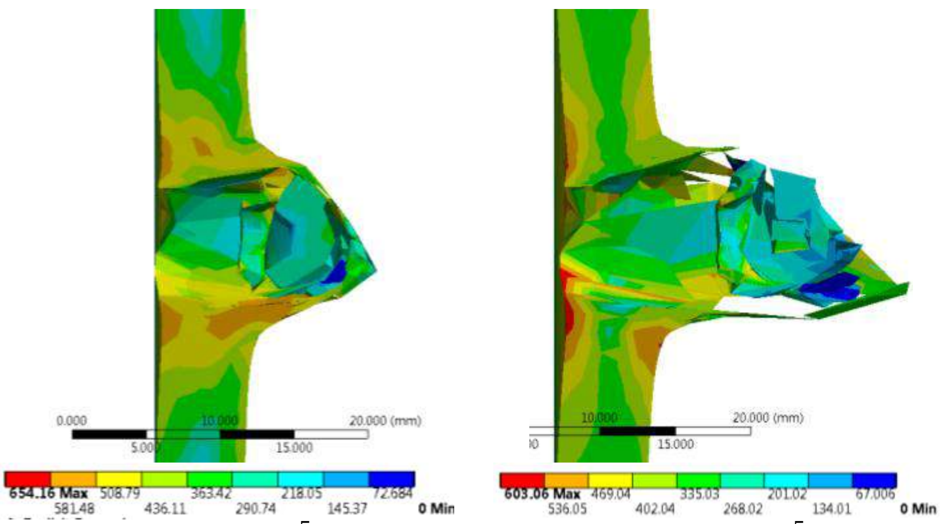


Fig. 6. Total energy versus configuration

The energy absorption on a single plate between soft plate (S) is smaller than the hard plate (H). However, for layered-plate configurations the average high energy absorption occurs on the plate using the soft configuration. The greatest energy occurs in the S2 consolidation on the soft-rubber-soft plate panel with the addition of 2 mm thick rubber. The same is true for the hard configuration plate, where the highest total absorbed energy in the H2 configuration was achieved through adding 2 mm of rubber.

Fig. 7 shows the equivalent stress when the energy reaches the maximum value and the stable value after the maximum in the S configuration. Fig. 8 shows the same conditions in the H-configuration and Fig. 9 shows equivalent stress on the S2 and H2 configuration plates. The color of the simulation results shows the distribution of the received voltage of the plate due to the projectile impact force. Red color shows higher concentration of force while blue color shows lower concentration of force.



t=3.10×10^{-5} t=6.38×10^{-5}

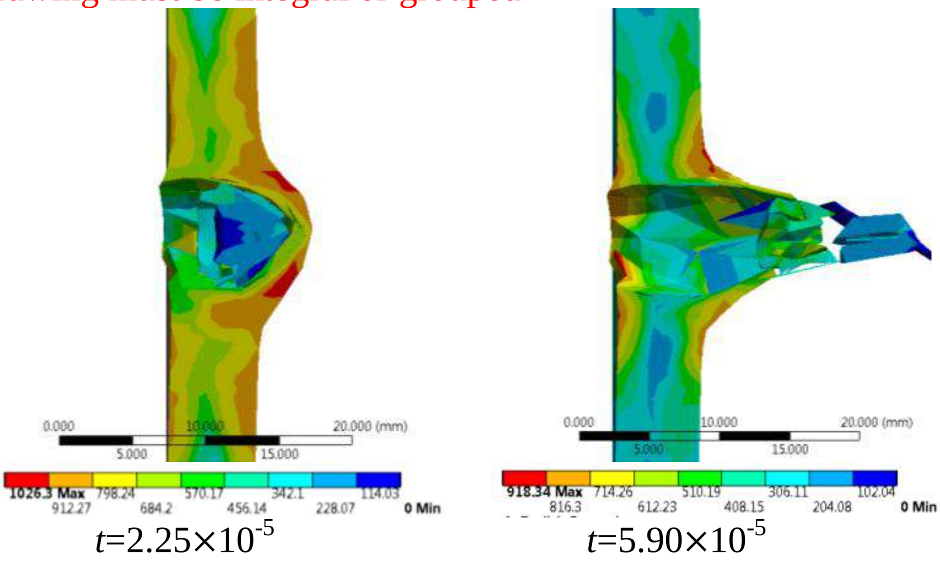
a b

Fig. 7. Equivalent stress on a single configuration plate S: *a* – when the maximum absorption energy is reached; *b* – the absorption energy stabilizes

Poor picture quality

The drawing should not be placed in a table

The drawing must be integral or grouped



a b

Fig. 8. Equivalent stress on single configuration plate H: *a* – when the maximum absorption energy is reached; *b* – the absorption energy stabilizes

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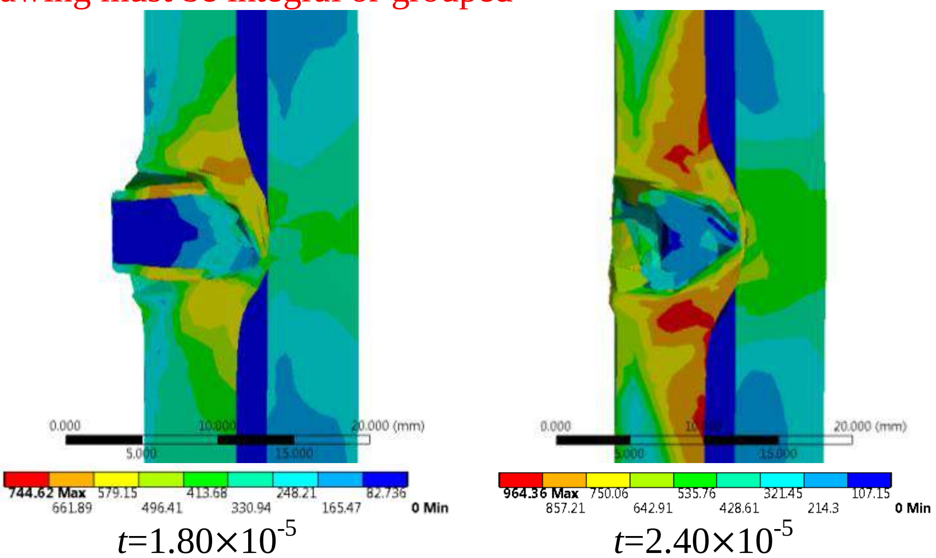

a b

Fig. 9. Equivalent stress on layered plates when maximum absorption energy is reached: *a* – S2 configuration; *b* – H2 configuration

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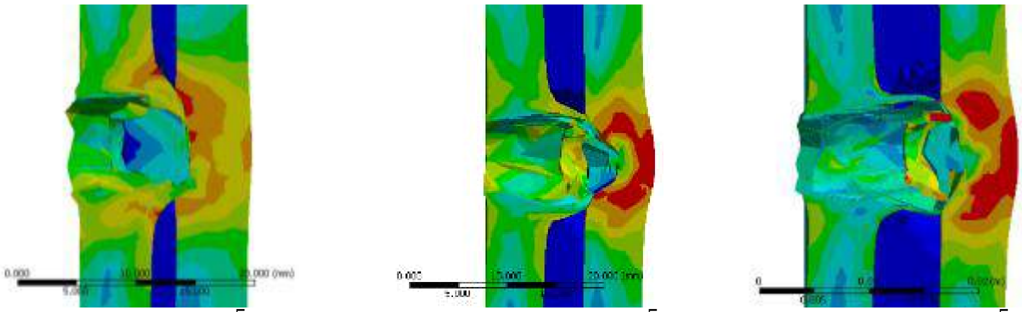
Fig. 10 shows the end simulation results on the plated plates S2, S4 and S6 configurations. Visible addition of rubber thickness between plates causes increased equivalent stress on the back plate.



t=4.8001×10^{-5} *t*=4.8001×10^{-5} *t*=4.8001×10^{-5}

abc

Fig. 10. Equivalent stress on layered plates end of simulation *t*=4.8001×10^{-5} : *a* – S2 configuration; *b* – S4 configuration and *c* – S6 configuration

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The drawing must be integral or grouped

7. Discussion of the absorbers energy

The maximum energy absorption on a single configuration plate S occurs at approximately seconds to 3.1×10^{-5}. And after reaching that time the energy absorption decreased. This is because at that moment the projectile has penetrated the plate in a single configuration as shown in Fig. 7 .The impact of a large projectile cannot hold the panel so that the panel reaches its maximum voltage and the panel is pierced after a second to 6.38×10^{-5} .After the seconds and the projectiles have passed through the panel, the remaining energy is proved by the tension still visible on the plate (Fig. 7, *b*).

This is also the case with single H configuration plate. The maximum energy occurs just before the projectile passes through the plate as shown in Fig. 8a. this process occurs at seconds to 2.25×10^{-5}. Also visible voltage on the plate reaches the maximum around the impact of the projectile. The energy decreases and is relatively stable after 5.90×10^{-5} seconds, this occurs after the projectile passes through the plate as shown in Fig. 8, *b*.

In contrast to the plated plates, energy rises significantly shortly after the projectiles consume the panel until it reaches a certain number and then tends to be constant. This boundary mark with a perverted projectile will pierce the front plate in a layered configuration. In the S2 configuration panel this condition occurs at 1.80×10^{-5} seconds as shown in Fig. 9, *a*, as seen from the projectile condition will penetrate the front plate.

In H2 configuration, the process occurs similarly to the S2 configuration. Energy rises significantly shortly after the projectile strikes the plate up to a certain value. The limit of increase until it reaches energy that tends to constant occur at seconds to 2.40×10^{-5} .This condition occurs when the projectile is capable of piercing the front plate in the H2 configuration as shown in Fig. 9, *b*.

The larger S2 configuration absorbs the impact energy of the bullet (Fig. 6), this is because the S configuration consists of soft-rubber plates and soft plates. The soft plate energy impeller is larger than the hard plate (Table 1) in the H configuration the addition of rubber thickness increased to 6 mm actually weakens the layered plate structure which causes the total energy to decrease compared to rubber thickness of 2 mm.

The addition of rubber to the layered plate arrangement can improve the absorption of ballistic impact energy. The rubber between the plates can absorb the collision energy of the plate, so that the impact energy is not directly forwarded to the next layer plate. This is because rubber is an elastic material and has good energy absorption. However the addition of thickness to 4 mm and 6 mm of rubber precisely absorption of energy collisions decreased. This is because rubber has non-rigid properties and is not resistant to penetration. The addition of rubber thickness between the two plates causes an increase in weak space so that the first plate fragments and the projectiles penetrating the first plate stronger push the back plate. This shows the equivalent stress on the back plate at the end of the simulation as shown in Fig. 10. So that the optimum energy absorption on the addition of rubber with a thickness of 2 mm, both in soft plate configuration (S configurations) and hard plate (H configurations).

Type of rubber can affect the energy absorption, because each type of rubber has different elasticity properties. The selection of rubber types in this study is not a concern, so the effectiveness of energy absorption by rubber cannot be analyzed further. The bolt tightening system in panel making can also be varied, because bolt system makes the impact vibration propagation different. With the addition of increasingly complex boundary conditions then the simulation will get more complete data but require long simulation calculations and requires a computer with higher specifications.

8. Conclusion

1. Experimental and simulation results ballistic impact tests look similar. The level of similarity of ballistic impact is 93 % or with error 7 %.

2. Energy due to the impact ballistic received and absorbed on the panel rises significantly shortly after the collision. On a single plate, this occurs until it reaches a certain number then the energy will decrease because the projectile succeeded in penetrating the plate. While on the layered plate, after the projectile successfully penetrates the front side plate, absorption energy reaches the maximum number and then remains constant until the end of the simulation, which caused the projectile to be unable to penetrate the next plate layer. And optimal absorption of energy by plate occurs in the addition of 2 mm of rubber either on soft plate or hard plate layer.

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