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Finite Element Analysis of Armor Piercing Bullet Penetrating Hard Steel Armor Plate

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Received 19 April 2022; Revised 19 May 2022; Accepted 20 May 2022

Abstract

The bulletproof plates with materials that can convincingly be destroyed by the 7.62 mm bullet with its speed at 878 ± 9.1 m/s were developed by designing according to the National Institute of Justice Level 4 (NIJ 4). The plates were made of two flat sheets stacking, SKD11 and SUS304. Their components were composed of the front and back plates; the first sheet made of SKD11 material hardening at 65 HRC with a thickness of 6 mm and the back plate made of SUS 304 material with a thickness of 5 mm. The finite element method was applied to simulate and analyze the results to demonstrate the bullet resistance to the perforation by setting perpendicular sheet to the bullets. Therefore, the simulating studies for the bullet firing were demonstrated by locating its angles of 15, 30, 45 and 60 degrees to the SKD11 sheet with a thickness of 6, 8, and10 mm coupled with the SUS304 sheet with a thickness of 5, 6, 8, and 10 mm. These plates were stacking into two layers then the finite element method was applied to simulate one at a time. The results showed that the first sheet of SKD11 with 6 mm of thickness could resist the perforation of the bullet at 60 degree and the plate thickness of 8 and 10 mm could start resisting to the perforation at 45 degree. The second sheet of SUS304 with the thickness of 5, 6, 8, and 10 mm were incapable to resist to the perforation and the refraction of the bullet direction as good as that of SKD11. Therefore, the principle applying two metal sheets stacked into layers was essential to impel the resistance of the bullet perforation and change the direction of the bullet.

Keywords : 7.62 mm Bullet, NIJ 4, Bulletproof Plate, Finite Element Method

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1. Introduction

Development and design of bulletproof armor plates with materials was performed to understand the armor behavior in destroying of 7.62 mm bullets. The finite element simulation was applied to analyze the thickness parameters affecting on the penetration resistance. A.M. Iqbal et al. [1] had simulated the durability behaviors of 12 mm and 16 mm thicken-steel plates affected by a 7.62 AP bullet at different speeds and angles. From the test, the brass sleeve was removed from the outer bullet and only the internal metal bullet left was chosen for studying its banging behaviors to the metal armor plate. The studied criteria were based on the simulation consisting of the metal thickness at 12 mm and 16 mm, the plate size at 200 x 200 mm, the bullet with its size of 6.06 mm, and total length of 28.4 mm at the speed of 818 m/s.

The selected element for the bullet was hexahedral with the size of 1 mm^3. Also, the other sizes were 0.8, 0.6, 0.2 and 0.1 mm^3. The tests were done at the plate target of 12 mm thickness and the remaining speeds for those sizes were observably decreased by 669, 663, 658 and 657 m/s, respectively. The armor plate was made of a tetrahedral mesh of size 0.2, 1, and 2 mm^3. The calculated procedures for the test took 5 hours for the thickness of 12 mm and 9 hours for the thickness of 16 mm. The tested plate thickness was 12 m with a 45 degree for collision angle causing the actual test speed at 555.3 m/s. In addition, the simulated speed with the program was at 515.82 m/s, displaying 7.6% difference from the actual speed. From the actual experiment of the collision with a tilt angle of 57 degree, the bullet speed was reduced to 368.9 m/s and the thickness of the armor plate was 16 mm. The simulated results indicated that the bullet was embedded in the armor plate whereas the experiment results were different due to a 6% increase in bullet embedding if using a bullet shooting at 51 degrees. The simulation for bullet buried in the armor plates was performed for the bullet piercing through a 12 mm thick plate. The perforation on the piercing back was appeared to be smaller than the front piecing, looked like an oval shape. T. Børvik et al. [2] had examined the impact of bullet shot on aluminum plates AA6082-T4 at 20 mm thickness using experimental and simulation methods. Two bullet sizes applied for the tests were 7.62 x 51 mm and 7.62 x 63 mm. The detected impact speed was also set at 830 m/s for all tests. During the tests, the bullet velocity started and ended was recorded. Their speeds were measured by many types of laser-based optical devices using a high-speed video camera. The photographs of the armor penetration process, particularly relevant to the important parts, were made for the observation the effects of tilted angles in which influence the various penetration results. The studies were observed for the the inclination angles of less than 60 degrees and the change in penetration behaviors accounted to be the perforation, implantation, or reflection.

T. Binar et al., [3] simulated with the LS-Dyna program demonstrated whether the armored materials were damaged increasing or not it was depending on the change in temperature. As the temperature rises, the deep penetration of the bullet increases. If the temperature drops, the deep penetration decreases. In summary presents that Element mesh is very important, mesh sizes varied for different mesh damage were displayed as expected in that the stress value could cause an increase in DOP value correctly when mesh sizes were created at very fine (0.5 x 0.5 x 0.5 mm), fine (1 x 1 x 1 mm), rough (1.5 x 1.5 x 1.5 mm), and very rough (2 x 2 x 2 mm) particles.

2. Research Methodology

2.1 Material modeling

According to SKD11 plate model used for analysis of bulletproof armor, the material was chosen to indicate the bullet head destroyed and the impact to the armor plate 1. The bullet was broken into pieces and penetrating to the armor plate 2. For the armor plate 1, the analyzed SKD11 material with the hardness standard specification of 60-62 HRC (Rockwell scale C), the thickness of 3 types – 6, 8, and 10 mm, the size of 30 x 30 cm, and the tilt angle of 60 degree, was performed according to Johnson-Cook Model (JC) of failure. These possessed criteria were described by an equation below. [4]

$$\sigma = [A+B(\varepsilon_p)^n][1 + C \ln (\dot{\varepsilon}/\dot{\varepsilon_0})][1 - \{(T-T_0)/(T_m-T_0)\}^m] \quad (1)$$

Where A is initial yield stress, B is hardening constant, ε_p is equivalent plastic strain, n is hardening exponent, $\dot{\varepsilon}/\dot{\varepsilon_0}$ is reference strain-rate and $\dot{\varepsilon}$ is the plastic strain rate. In addition, C is the strain rate constant, m is temperature softening exponent, $(T-T_0)/(T_m-T_0)$ is a temperature absolute, whereas T, T_0 and T_m is temperature set at room temperature and melting temperature [4]

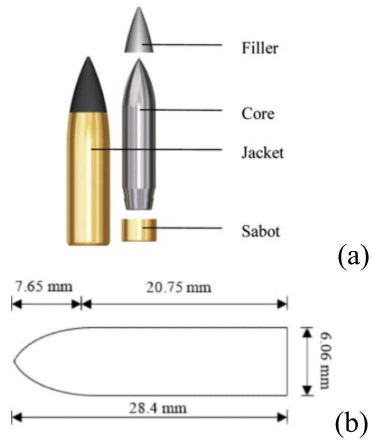


Fig. 1 Bullet structure (a) assembly of bullet [2] (b) dimension of bullet [5].

Table 1. Properties and parameter JC of SKD11 (60-62 HRC) [6]-[8]

Properties	SKD11
Density (ρ, kg/m^3)	8400
Modulus of elasticity (E, GPa)	208
Poisson ratio (ν)	0.3
Bulk modulus (GPa)	173
Shear modulus (GPa)	80
Thermal conductivity (W/m. k)	20.5 (350°C)
Thermal expansion (m/m. k)	11
Specific heat (J/kg. °C)	461
Johnson-cook strength	
Initial yield stress (A, MPa)	1766
Hardening constant (B, MPa)	904
Hardening exponent (n)	0.39
Strain rate constant (C)	0.012
Thermal softening exponent	3.38
Melting temperature (K)	1733

The simulated bullet had a size of 7.62 mm, shown in **Fig. 1**. The shell of bullet was removed, and only the core made from Tungsten carbide (WC) remained was analyzed for the effects of impact and the breaking behaviors on the armor, of which mechanical properties and parameters were described by simulations according to Johnson-Holmquist failure model (JH-2), shown in **Table 2**.

Table 2. Properties and parameter JH of tungsten carbide [7], [9]

Properties	Tungsten carbide
Density ($\rho, g/cm^3$)	14.56
Young's modulus (E, GPa)	539
Poisson ratio (v)	0.23
Bulk modulus (GPa)	332
Shear modulus (GPa)	219
Tensile yield strength (GPa)	3.85
Compressive yield strength (GPa)	4.53
Johnson-Holmquist Strength (Continuous JH-2)	
Damage type	Gradual (JH2)
Hugoniot elastic limit (HEL, GPa)	656
Intact strength constant (A)	0.9899
Intact strength exponent (n)	0.0322
Strain rate constant (C)	0
Fracture strength constant (B)	0.67
Fracture strength exponent (m)	0.0322
Maximum fracture strength ratio	1000
Damage constant (D1)	1
Damage constant (D2)	0
Hydrodynamic tensile limit (GPa)	-4

The equation of failure is demonstrated as follows.

$$Y = [A(p^* + T^*)^n(1 - D) + B(p^*)^m D][1 + C \ln(\dot{\varepsilon}_p^*)] \quad (2)$$

$$p^* = \frac{p}{p_{HEL}} \quad , \ T^* = \frac{T}{p_{HEL}} \quad (3)$$

When Y is yield stress, p_{HEL} is the pressure at Hugoniot Elastic Limit (HEL), T is Maximum hydrodynamic tensile strength, and A, B, C, n, m are parameters of materials. HEL could yield the limit at uniaxial strain when materials receive loads in one direction, therefore, there will be 2 equations for separating the yield stress, when D = 1 or D < 1 in Johnson-Holmquist, the Yield stress is continual failure function of D. Therefore, the types of materials of these properties are called "active" failure simulation. For special cases, when D = 0, there is no any damages, and when D = 1, there are damages according to the equation below. [6]-[9]

$$Y = A(p^* + T^*)^n[1 + C \ln(\dot{\varepsilon}_p^*)]$$
(Intact, D=0) (4)

$$Y = B(p^*)^m[1 + C \ln(\dot{\varepsilon}_p^*)]$$
(fragmented, D=1) (5)

For plate 2, SUS304 material was used to absorb the force of scattering broken pieces of bullet and showed the impact on the plate 1 penetrated out thoroughly. The size of plate was 30 x 30 cm, and its thickness from 5 mm was used for testing the normal SUS304 material with the thickness of 1 mm to 5 mm. After that, its thickness was changed to 6, 8, 10 mm etc. The thickness used in the simulation was 5, 6, 8, and 10 mm and the failure theory of Steinberg-Guinan Strength model was employed for situation of high strain ratio and extended to low strain ratio [10]. The equation is accomplished as follows.

$$G = G_0\{1 + \left(\frac{G_p'}{G_0}\right)\frac{p}{\eta^{1/3}} + \left(\frac{G_t'}{G_0}\right)(T - 300)\} \quad (6)$$

or

$$Y = Y_0\{1 + \left(\frac{Y'_p}{Y_0}\right)\frac{p}{\eta^{1/3}} + \left(\frac{G'_t}{G_0}\right)(T - 300)\}(1+\beta\varepsilon)^n \quad (7)$$

at $Y_0 = [1+\beta\varepsilon]^n \leq Y_{max}$

Table 3. Properties and parameter of SUS304 [7]

Properties	SUS304
Density (ρ, kg/m^3)	7900
Specific heat (J/kg.°C)	423
Shock EOS linear	
Gruneisen coefficient	1.93
Parameter (C1, m/s)	4570
Parameter (S1)	1.49
Parameter quadratic (S2)	0
Steinberg Guinan strength	
Initial yield stress (Y, MPa)	340
Max. yield stress (Ymax, GPa)	2.5
Shear modulus (GPa)	80
Hardening constant (B)	43
Hardening exponent (n)	0.35
Derivative (dG/dP, G'P)	1.74
Derivative (dG/dT, G'T, MPa/°C)	-35
Derivative (dY/dP, Y'P)	0.007684
Melting temperature (Tmelt, °C)	2106.9
Shear modulus (GPa)	77

Where ε is effective plastic strain, T is temperature (K), η is compression, and parameters of subscript p and t are derivatives for pressure and temperature that refer to those conditions (T = 300 K, p = 0, ε = 0). The subscription zero refers to the value of G and Y at those conditions. If the temperature of material is higher than the specific melting point, shear modulus and strength will be set to zero [7], [8]. The properties and parameters of SUS304 are provided in the finite element simulation software, shown in the **Table 3**.

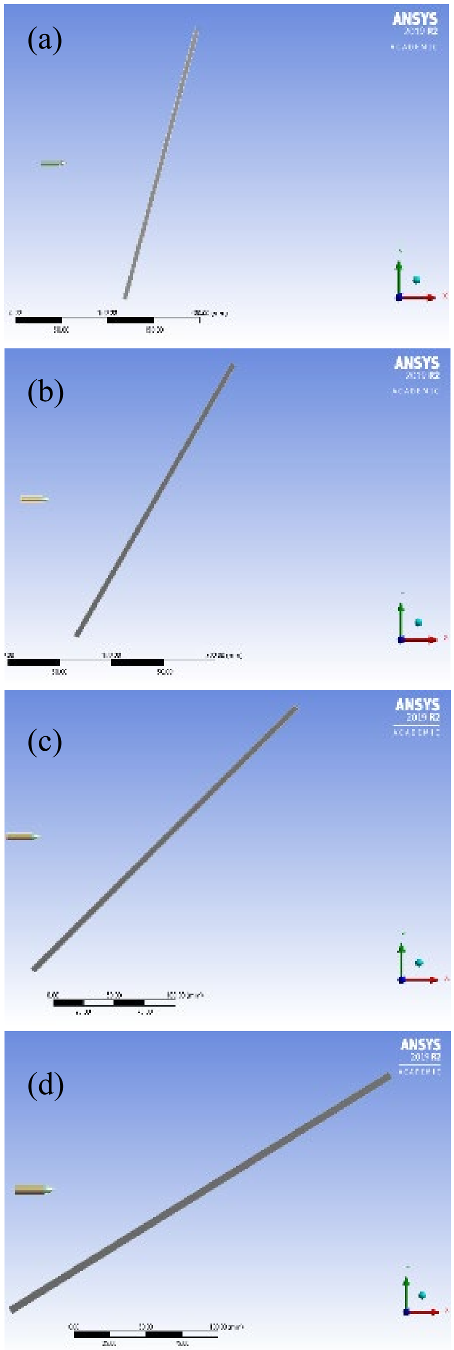


Fig. 2 Tilt angles in simulations: (a) 15 (b) 30 (c) 45 and (d) 60 degrees.

2.2 Numerical method

The finite element simulation using Ansys/Explicit dynamics software was used to simulate the conditions of shooting according to NIJ standard level 4, of which speed of bullet is 878±9.1 m/s compared to NIJ standard level 3, of which speed of bullet is 847±9.1 m/s [7], [8], at setting speed of 880 m/s and bullet size of 7.62 mm. The bullets made from WC were selected for 2 types of simulations. In the simulation 1, the materials for the armor plate 1 is SKD and that of the armor plate 2 is SUS304, of which tilt angles in simulation are set at 15, 30, 45 and 60 degrees, shown in **Fig. 2**. For the pattern of mesh, it was hexahedral at both the armor plate and bullet, of which a size of mesh at bullet was 0.5 mm and at the armor plate was 4 mm.

3. Results and Discussion

3.1 Simulation of NIJ standard level 4

In simulation 1 using SKD11 material at thickness of 6 mm with titled angles of 15, 30, 45, and 60 degrees, it was found that the tilted armor plates at angles of 15, 30, and 45 degrees were unable to endure the penetration of 7.62 mm bullet but would be able to break the bullet. Additionally, for a tilt angle at 60 degree, the armor plate was able to endure the penetration of bullet. It caused the impact angle to the armor and compelled the bullet break and change directions. The broken pieces of bullet metals moved towards the tilt angle of the armor could be demonstrated in **Fig. 3**. From **Fig. 4**, the graph displayed the tilt angle of 45 degree at the time step 18-20 ms. It was

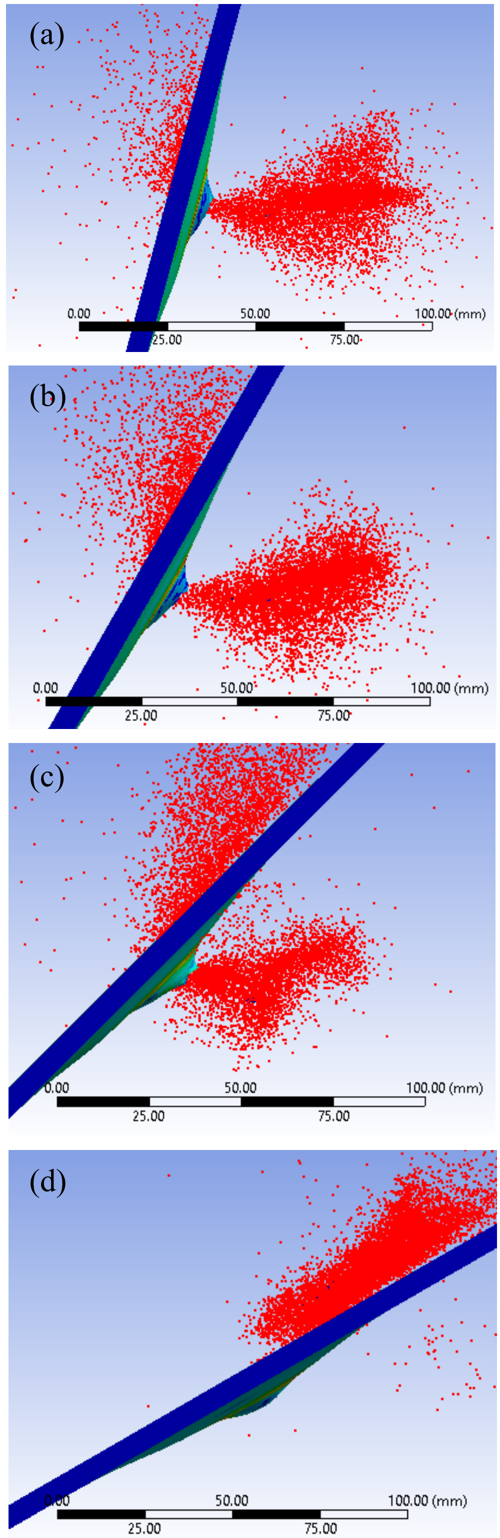


Fig. 3 Damages of armor plate with 6 mm thickness at step 22 ms (a) 15 (b) 30 (c) 45 and (d) 60 degrees.

found that its strain was predominantly at the highest-level contrasting from others tilted angles of 15, 30, 45, and 60 degrees. At these following angles, the observed armor plates had started to endure the penetration of bullet due to less deformation and increased in impact angles as shown in **Fig. 5**. Also, there were rebounding bullet happened at the front of the armor plate with the tilt angle of 60 degree and at the same time, the armor plate attained the strain accumulated increasingly and was appeared to endure the penetration. The situation thus caused a change in the direction of small pieces of metal bullets.

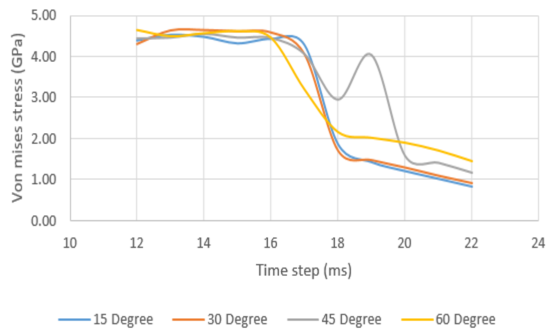


Fig. 4 A graph representing the stress of the SKD11 armor with 6 mm thickness.

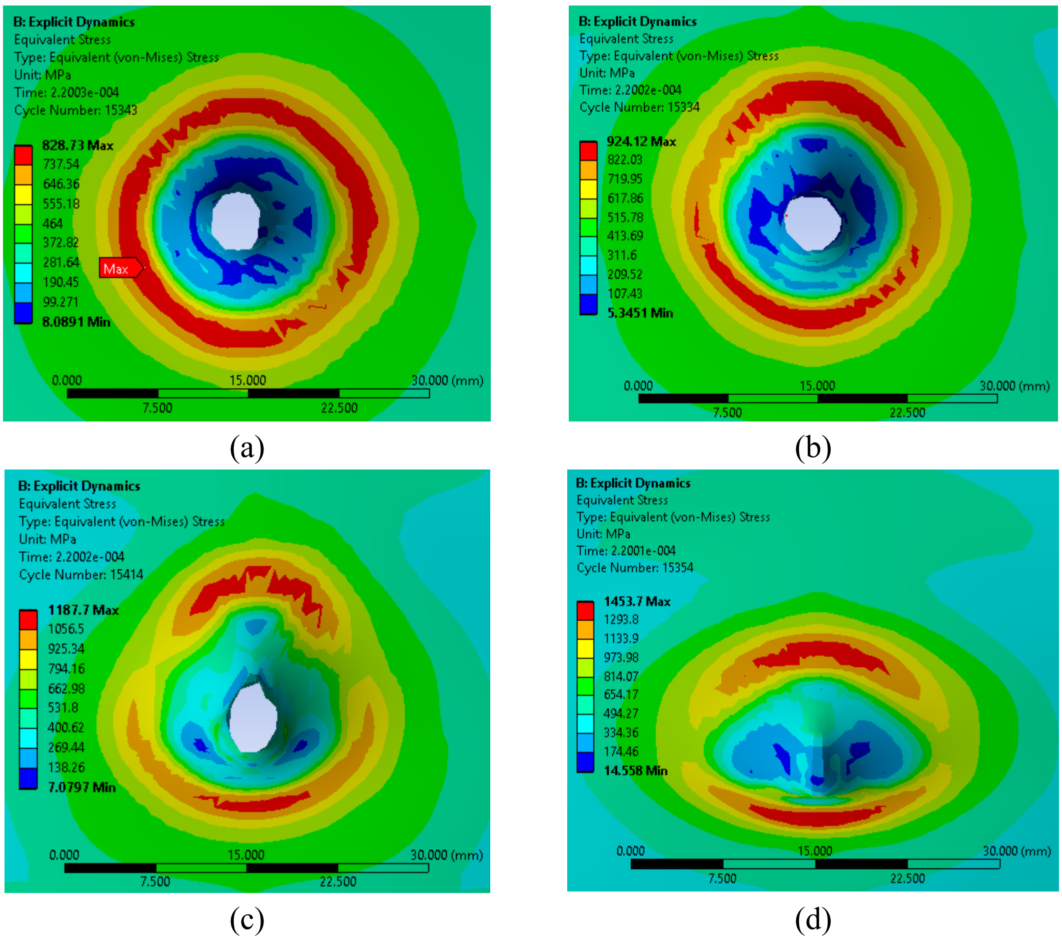
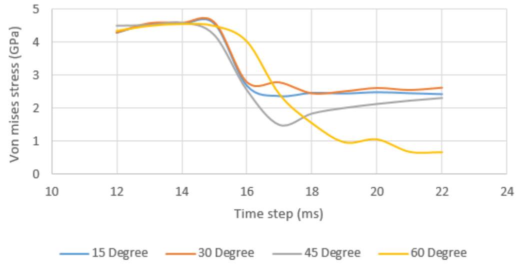


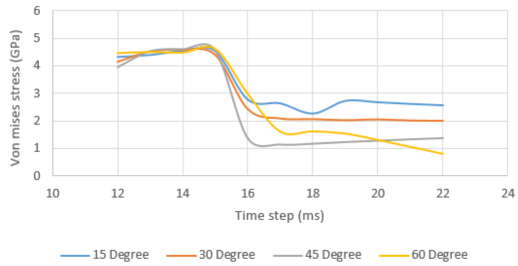
Fig. 5 Impact of bullet at the angles of 15, 30, 45, and 60 degrees at time steps of 22 ms (a) 15 (b) 30 (c) 45 and (d) 60 degrees.

For the experiment using the thickness of 8 mm and tiled at the angles of 15, 30 degrees, the plates were in tolerant to all penetration of the bullets. At the tilt angles of 45 and 60 degrees, the armor plates could evenly endure the penetration and change the directions of bullet heads. From the graph in **Fig. 6 (a),** the results exhibited the different strains for the tilt angles of 15 and 30 degrees. The less stress was taken place when the bullet had changed its direction, affecting the impact on to the armor plate and bringing up less deformation with higher impact angles of bullet head. For the strain at 15 and 30 degrees, the bullet could penetrate the armor plate thoroughly out. The strain was gained steadily because the armor plate was penetrated without any deformation in long term investigation. **Fig. 6 (b)** indicated that the armor plate with 10 mm thickness could resist the penetration of 7.62 mm bullet. It caused the bullet broken into small pieces of metals. From this graph, the performances applied the tilt angles of 15, 30, and 45 degrees showed that the bullet had impacted to the armor plate by increasing impact angle and thus causing the strain decreased according to increases in the tilt angles.

However, at the tilt angle of 60 degree, the bullet had impacted, the strain was decreased slower than those tilted at the angles of 15, 30, and 45 degrees. This was because of the change in the direction of small pieces of the bullets and having less deformation, shown in **Fig. 7.**



(a) The armor plate with 8 mm thickness.



(b) The armor plate with 10 mm thickness.

Fig. 6 Graph representing the strain of the SKD11 armor plate.

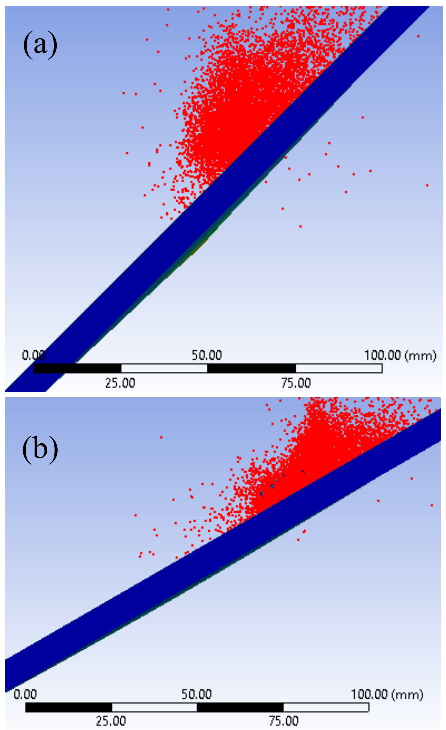


Fig. 7 Change in directions of bullets (a) 45 and (b) 60 degrees.

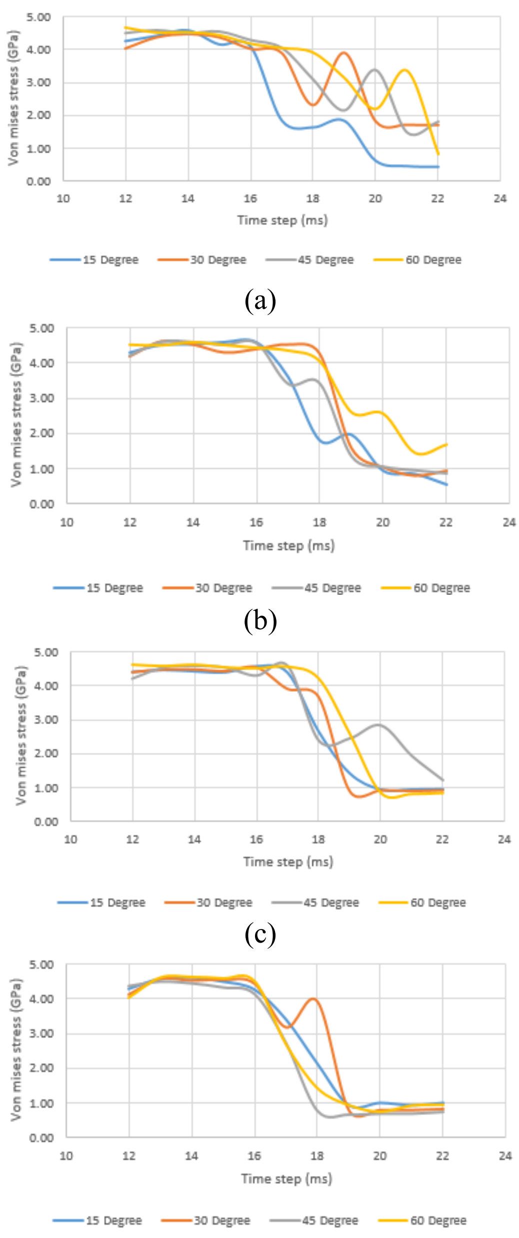


Fig. 8 Graph representing the strain in SUS304 armor plate with (a) 5, (b) 6, (c) 8, and (d) 10 mm thickness.

For SUS304 armor possessing the tilt angles of 15, 30, 45, and 60 degrees together with either 5, 6, 8, and 10 mm thickness, all observed simulations demonstrated that the plates could endure the penetration of 7.62 mm bullet. From **Fig. 8**, at 6, 8, and 10 mm thickness and having impact of the bullets, the similar results were dominantly expressed since the observed strain seemed indifferent from other armor types.

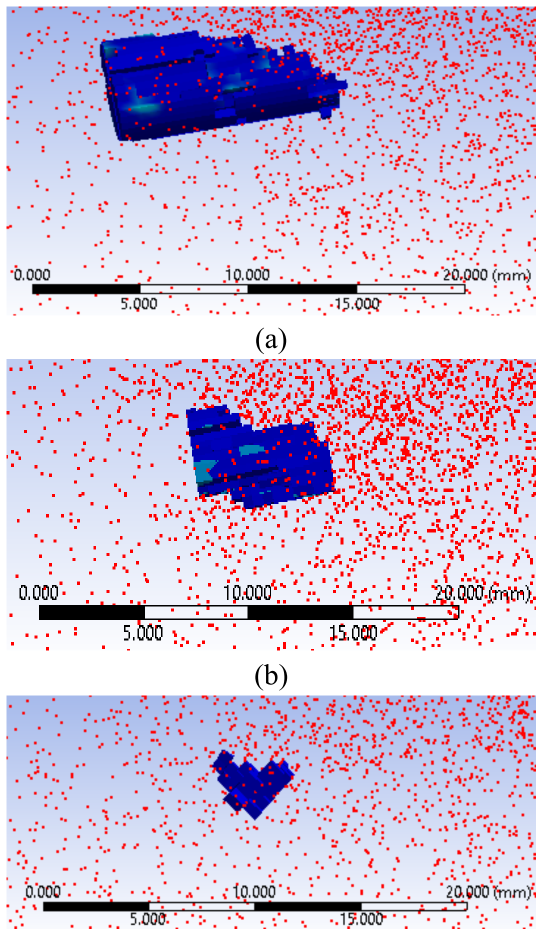


Fig. 9 Penetration of the bullet into the armor plate at a tilt angle of 15 degree and thickness of (a) 6 mm (b) 8 mm and (c) 10 mm.

At the angles of 15, 30, 45, and 60 degrees, after hitting to the armor, the bullets were broken in to large pieces and penetrating through the armor. Its particle sizes were smaller even if increasing in the armor thickness, illustrated in **Fig.9**.

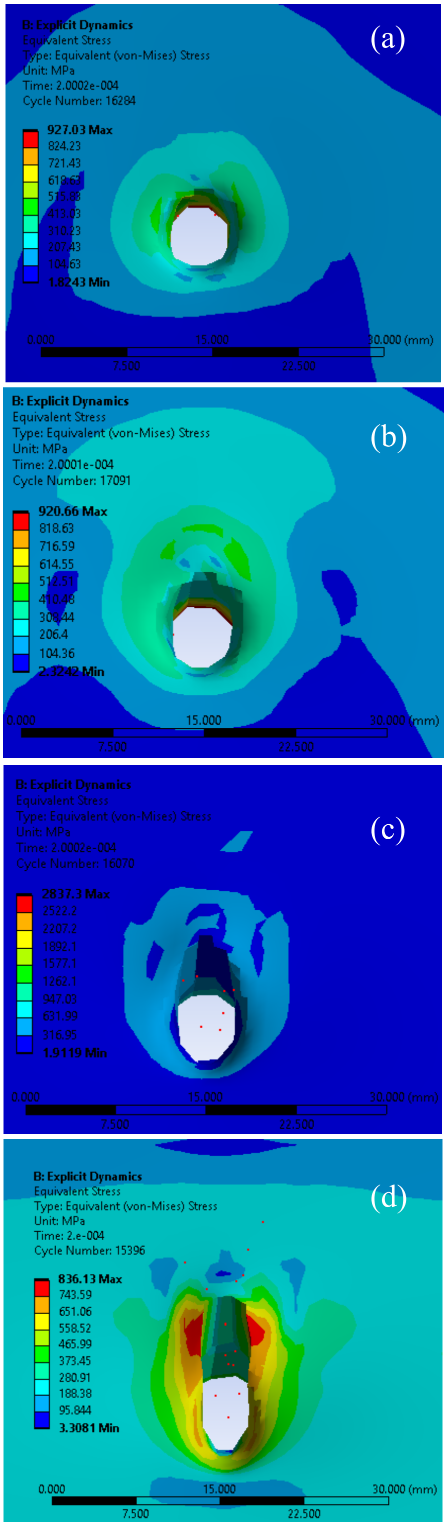
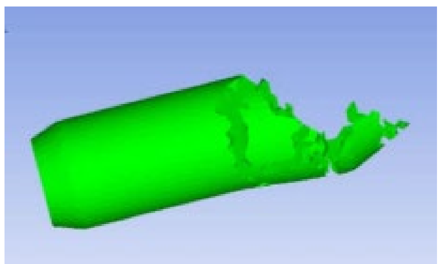
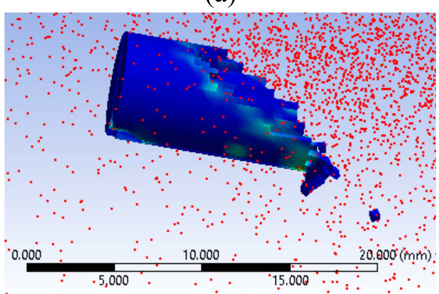


Fig. 10 Impact tracing of the bullet on the armor with 8 mm thickness at time step 20 ms and at tilt angle of (a) 15 (b) 30 (c) 45 and (d) 60 degrees.

More prominent deformation was created on the penetrated traces and holes in SUS304 armor plate than SKD11 armor plate because the SUS304 is softened in property. It can then assist in holding the bullet and resulting more damages on the armor, shown in **Fig.10**. However, the bullets would be broken severely if the plate thickness was increasing. The increase in thickness of the armor intensified more bullet breaking into large numbers of pieces due to softening property of the armor. However, if less thickness of the armor was chosen, more built up softening property of the armor was. These significances leaded to opposite results in that the bullet would be broken into larger pieces.



(a)



(b)

Fig. 11 Simulation of the bullet after penetration to the armor tilted at the angles of 15, 30, and 45 degrees, (a) damages of the bullet described by F. M. John et al. [9] and (b) damages of bullet produced by our study.

At the thickness of 5 mm of the armor with tilt angles of 15, 30, and 45 degrees, the bullet caused impact directly to the armor plate. The bullet would be damaged, and broken into large pieces of metals before penetrating into the armor. Its shape was still be the bullet like particle but the penetrated direction of the metal pieces was changed slightly. Therefore, when compared to model of F. M. John et al. [9], their results of bullet appearance after penetrating through the armor plate were similar to our findings shown in **Fig. 11**.

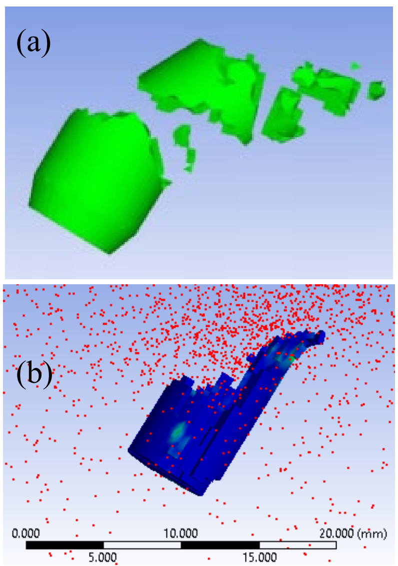


Fig.12 Simulation of the bullet after penetration to the armor tilted at the angles of 15,30, and 45 degrees, (a) damages of the bullet described by F. M. John [9] and (b) damages of bullet produced by this study.

At the angle of 60 degree, after penetration through the armor plate, the bullets were changed in their direction clearly. They were further broken into a group of large pieces of metals, explained in **Fig. 12** The bullet appearances were similar to those at the tilt angle of 18 degree determined by F.M. John et al. [9]

Two plates stacked together into two layers were designed, of which the front plate was SKD11 whereas the back plate was SUS304. Thickness of the first plate, t_1, was of 6, 8, and 10 mm. Thickness of the back plate, t_2, was 5, 6, 8, and 10 mm. For simulation test tilt angles at 15, 30, 45, and 60 degrees, the results from simulation process were determined for the thickness of the condition with $t_1 = 6$ mm and $t_2 = 5$ mm and with $t_1 = 6$ mm and $t_2 = 6$ mm, at tilt angles of 15 and 30 degrees. The armor plates were unable to endure the penetration of bullets. The broken bullet into pieces of metal were clearly observed. Then these pieces were penetrated into the armor. The tilt angle of 45 and 60 degrees oppositely caused the bullet penetrate through the armor and change in the direction of small pieces of bullet metals broken before moving along the tilt angle of metal. The results were illustrated in **Fig. 13**.

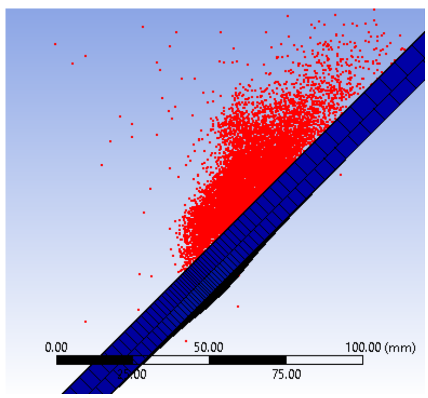
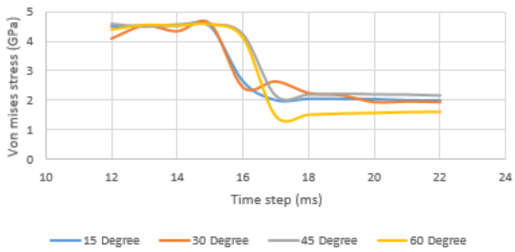
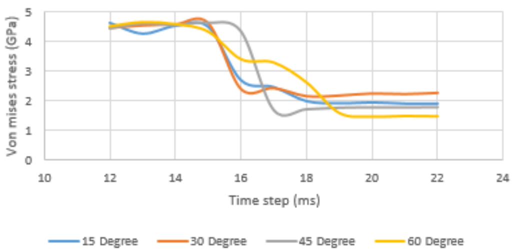


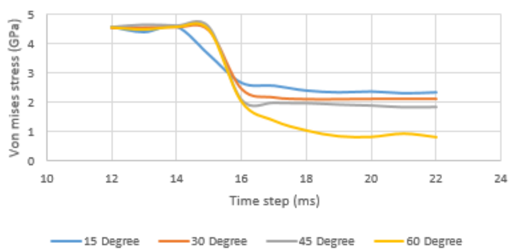
Fig. 13 Appearances of a group of broken small pieces of metals when impacted to armor plate with various thickness at 45 degree.



(a) SKD11, t_1 = 6 mm and SUS304, t_2 = 5 mm.



(b) SKD11, t_1 = 6 mm and SUS304, t_2 = 6 mm.



(c) SKD11, t_1 = 8 mm and SUS304, t_2 = 8 mm.

Fig. 14 A graph of the strain vs time step of 2 layered armor.

For the thickness of t_1 = 8 mm and t_2 = 8 mm at tilted angles of 15, 30, 45 and 60 degrees, the armor plates were impenetrable to 7.62 mm bullet and there was changes in directions of a group of small pieces of metals after impact on the armor plate. In **Fig. 14 (c)**, the strain had risen from the impact of bullet, thus decreasing and remaining constant. The step of decreased strains was occurred according to increases in tilt angles or impact angles of the armor plates. In addition, the results shown in **Fig.14 (a)** and **(b)** specified that the strain at angels of 15 and 30 degrees decreased faster than those of 45 and 60 degrees because the armor plate was not be penetrable then the strain was accumulated more at the inside plate, then be unchanging after the armor plate was penetrated. For the angles of 45 and 60 degrees, the plates were able to endure the penetration, thus, the strain decreased slower than that of 15 and 30 degrees because of more accumulated strain at the armor plate. The thickness of t_1 = 10 mm and t_2 = 10 mm, also absolutely influenced the penetrating resistance especially, at its thickness of t_1 = 8 mm and t_2 = 8 mm, the armor presented well endurability in penetration of the bullet. The armors plates composed of 2 layers of 8 mm plate could even better endure the penetration at tilt angles of 15, 30, 45 and 60 degrees when impacts happened. Additionally, in simulation of impact from tilt angles, the bullets were enforced to change in direction after penetration through the armor that were dependent on particular tilt angles and thickness. These parameters affected the decrease in the speed of bullet after impact [11].

3.2 Comparison with NIJ standard level 3

For the simulation according to NIJ standard level 3, the speed was simulated set at 847 m/s for either armor using of 1 layered plate or 2 layered plates, of which all parameters including tilt angles, materials and thickness of the armor were the same as previously used in the standard level 4. In this case, the armor plate was SKD11 with thickness of 6 mm, and tilt angles was at 15 and 30 degrees. The results demonstrated that the armor plates were penetrated. In the other case, at tilt angles of 45 and 60 degrees, the armor plates could not be able to resist the penetration and caused the bullet change its direction when impact on the armor plate. In the test using thickness of 8 mm and tilt angle of 15 degree, the armor plate showed opposite behavior in that it did not tolerate to the penetration whereas this plate tilted at the angles of 30, 45 and 60 degrees could withstand the penetration. These results were different from those determined in the NIJ standard level 4 applying the conditions of the thickness of 6 mm and the angle of 45 degree (**Fig.15**) as well as thickness of 8 mm and tilt angle of 30 degree and (**Fig. 16**).

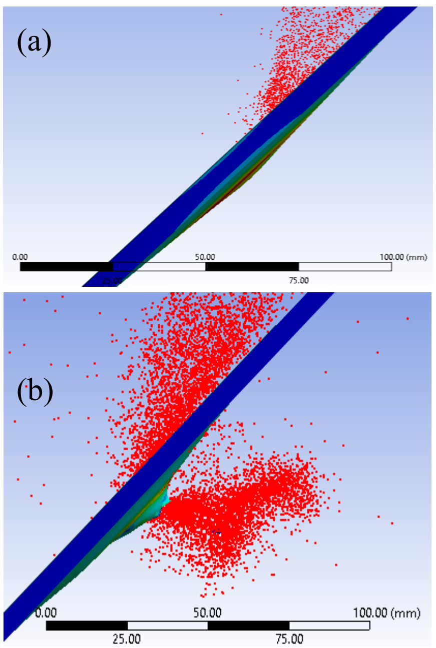


Fig. 15 The simulations for the time step 20 ms (a) according to NIJ standard level 3, using tilt angle of 45 degree and (b) according to NIJ standard level 4, using tilt angle of 45 degree.

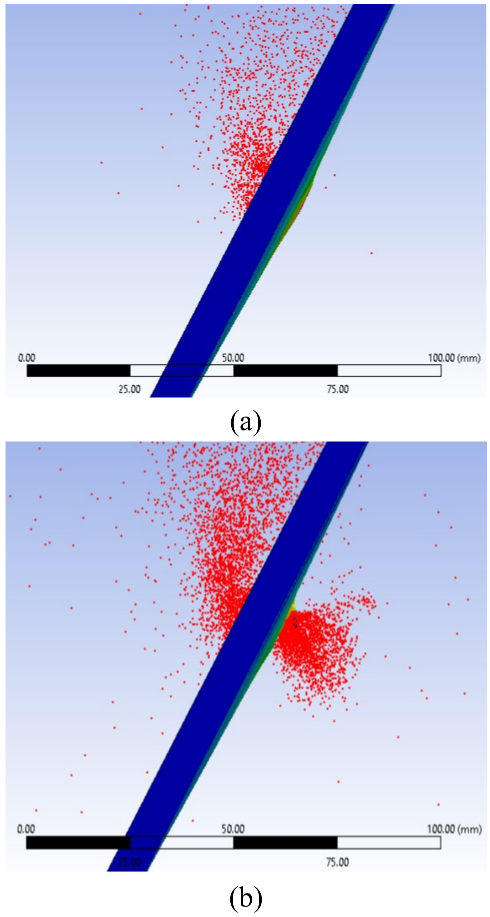


Fig. 16 The simulations for time step 20 ms (a) according to NIJ standard level 3, using tilt angle of 30 degree (b) according to NIJ standard level 4, using tilt angle of 30 degree.

For armor plate of SUS304 having the thickness of 5, 6, 8, and 10 mm and tilt angles of 15, 30, 45, and 60 degrees, compared with that determined by NIJ standard level 4, all armor plates could prevent the penetration **(Fig. 17)**. Therefore, there were no significant differences in their simulation results.

Using two layered armor plates, the front plate made of SKD11 and the back plate made of SUS304, of which thickness were performed at t_1 = 6 mm, t_2 = 5 mm

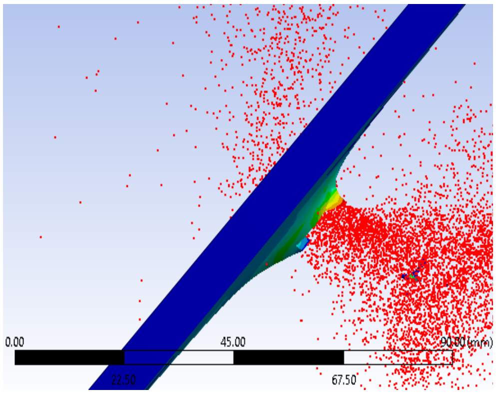


Fig. 17 Armor plate with 8 mm thickness and a tilt angle of 45 degree at time step 20 ms.

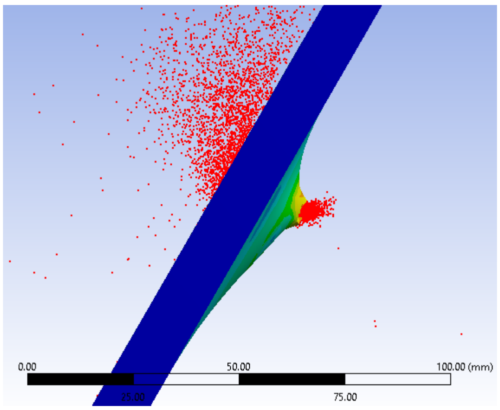


Fig.18 Armor plate with $t_1 = 6$ mm, $t_2 = 6$ mm, a tilt angle of 30 degree, time step 20 ms.

and $t_1 = 6$ mm, $t_2 = 6$ mm and tilt angles of 15 and 30 degrees (**Fig. 18)**, the results showed that the armor plates were penetrated. In the contrast, the tilt angles of 45 and 60 degrees induced the armor plates to resist to the penetration of the bullet when setting at $t_1 = 8$ mm, $t_2 = 8$ mm and tilt angles at 15, 30, 45 and 60 degrees. These data were expressively correspondent to the results established by NIJ standard level 4.

Therefore, the armor plate at a thickness of 12 mm was compared to that of M.A. Iqbal et al. [1] The penetration characteristics at the back of the armor plate had a smaller hole than that in the front plate, a fire element simulation that is close to the actual experiment as shown in **Fig. 19**, so the studied simulation can be used to analyze the destructive situation occurring on the armor plates before developing a real armor plate.

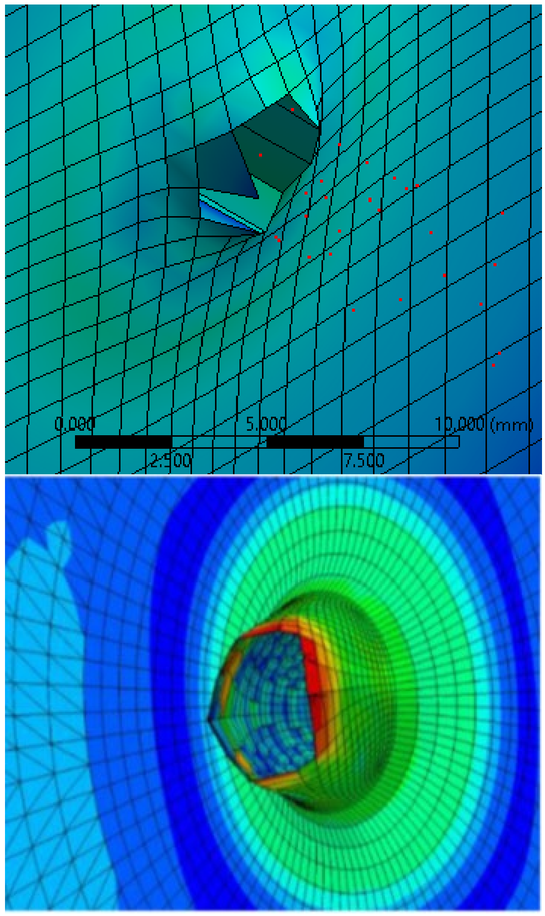


Fig. 19 The resulted WC and SUS 304 armor plate 2 with thickness of 12 mm after penetration (Above) compared with simulated plates of mild steel with thickness of 12 mm determined by M.A. Iqbal et al. (Below) [1].

4. Conclusion

The simulation of armor plates composed of two types of materials: SKD11 at thickness 6, 8 and 10 mm and SUS304 at thickness 5, 6, 8 and 10 mm together with the use of various collision angles in the simulation at 15, 30, 45 and 60 degrees were evaluated by applying with finite element method. The simulation at 15 and 30 degrees for the collision angle on the armor plate made of the SKD11 material could be clearly detected. At thickness of 6 and 8 mm, the armor could not resist to the penetration but causing the bullet broken into small metal pieces. The armor made of SUS304 material at thickness of 5, 6, 8 and 10 mm could not resist to the penetration. The bullet was broken into large metal pieces, thus penetrating the plate. Their smaller perforating sizes were observed when the thickness of the armor plate increased. However, a thin armor plate used could change the direction of broken large bullet pieces more than a very thick armor plate. The simulations at the 45 and 60 degrees of the collision angles indicated that one type of armor plates made of SKD11 material with 8 mm thickness could resist the penetration and refract the bullets. In addition, the bullet broken into small metal piece would be slipping out along the tilt angle. The other armor plate type using SUS304 material could not resist penetration thus be damaged in the piercing area greater than those tilted at the angle of 15 and 30 degrees. Since the SUS304 plate showed more softening effect than SKD11 plate, thus allowing more bullet holding and increasing the damage on the armor plate. The armor plates made of SKD11 material at the thickness of 10 mm could resist penetration through every degree. From the simulation of two layered stacking having tilt angle of 15 and 30 degrees and the thickness of t_1= 6 mm, t_2 = 5 mm and t_1= 6 mm and t_2= 6 mm, the plates could not resist the penetration of the bullet. The results of the impact angle modification in this study are consistent with those of P. K. Gupta et al. [12] and M. A. Iqbal et al. [13]. However, the plates titled at 45 and 60 degrees could withstand the penetration of the bullet. The armor plate having a thickness of t_1 = 8 mm and t_2= 8 mm was all able to withstand the penetration of the 7.62 mm bullet in all angles. Therefore, the two layered plates with thickness more than t_1 = 8 mm and t_2= 8 mm would be able to resist the penetration of the 7.62 mm bullet at 878±9.1 mm in accordance with the standard measurement of NIJ 4.

5. Acknowledgement

The authors would like to express the appreciation to the National Research Council of Thailand (NRCT), National Research Policy and Strategy for the financial support according to the contract no. 47/2561 and Rajamangala University of Technology Phra Nakhon (RMUTP) for supportive facilities.

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