

PAPER • OPEN ACCESS

Study on the energy release rule of sniper projectile penetrating soft protective target

To cite this article: J M Li *et al* 2020 *J. Phys.: Conf. Ser.* **1507** 032034

View the [article online](#) for updates and enhancements.

You may also like

- [Parallel computing of SNIper based on Intel TBB](#)
J H Zou, T Lin, W D Li et al.
- [The Application of SNIper to the JUNO Simulation](#)
Tao Lin, Jiaheng Zou, Weidong Li et al.
- [Common Envelope to Explosion Delay time Distribution \(CEEDTD\) of Type Ia Supernovae](#)
Noam Soker



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Study on the energy release rule of sniper projectile penetrating soft protective target

J M Li^{1,2}, W M Yan^{1,2}, F D Dong^{1,2} and Y J Qu^{1,2*}

¹Science and Technology on Transient Impact Laboratory, Beijing, 102202, China;

²No.208 Research Institute of China Ordnance Industries, Beijing 102202, China.

Email: lijnming51818@163.com.

Abstract. In order to investigate the penetrating mechanism of one sniper bullet against the gelatin target with soft armor under the condition of low speed, using gelatin as the imitation of biological targets, the energy release and transfer law were paid more attention. First of all the ultimate penetration velocity of the sniper projectile penetrating soft protection was carried out, with the ultimate penetration velocity was obtained, experiments and numerical simulation were carried out on the impact of the sniper projectile to soft protective gelatin below the velocity. The simulation results and test results were compared with the sniper projectile deformation and penetration of soft protective layer, gelatin bulging size, verified the accuracy of the numerical simulation. Thus further analysis with the result of numerical simulation, the stress, energy transfer and energy changes of soft protective gelatin penetrated by sniper projectile under non-penetrating conditions were analyzed, and the absorb energy law and the energy dissipation law of soft protective and gelatin in the process were obtained. The results showed that the main reason for the energy dissipation was bullet deformation. Under direct penetrating conditions, the energy of soft protective and gelatin increased with the increase of velocity, while the energy dissipation of sniper projectile also increased. The larger the penetration angle, the energy absorption of gelatin decreases with the increase of the penetration angle, energy dissipation of sniper projectile and energy absorption of soft protective were increased. The results can provide technical guidance for bullet design and individual soldier protection design.

1. Introduction

Body armor is not only an important part of individual protective equipment on the battlefield, but also plays a significant role in reducing casualties and increasing combat effectiveness, it is also used by criminals in all kinds of shooting cases, especially soft body armor. Soft body armor is further referenced as concealment body armor, which has the characteristics of concealment wearing and is widely used by all kinds of personnel for basic protection. Made of UHMWPE fiber with the highest specific strength and modulus, this kind of body armor provides effective protection against lead core pistol, low-speed fragment, low-speed lead core rifle bullet and drift bullet. Although the body armor can prevent the projectile from breaking down the protection, there is still some energy transferred to the body through the body armor deformation, resulting in organ damage. This phenomenon is known as blunt damage after body armor (BABT) [1-2].

In recent years, as Kevlar and UHMWPE fibers are widely used in soft bulletproof vests, the research on their protection mechanism and blunt damage has been widely concerned by scholars at home and



abroad. Among them, Gower [3] used numerical simulation method to analyze the penetration of 7.5mm cylindrical and conical projectiles into Kevlar fiber laminates. Xia Qingbo et al. [4] studied the penetration of steel cube into UHMWPE fiber laminate by using the finite element software, put forward the empirical model of the penetration of the projectile into the laminate, and analyzed the relationship between the penetration resistance of the projectile and the material parameters of the laminate. Naik et al. [5] studied the ballistic impact properties of woven composites, and established an analytical model based on stress wave theory and the energy conservation law. Huang Gongwu [6] carried out the numerical simulation of penetration of soft protective gelatin target with UHMWPE fiber, and carried out the experimental verification. Liu Kun [7] selected 9mm all copper bullet and small caliber lead core pistol bullet as the killing object, and carried out a numerical calculation and experimental verification of the soft protection movement model of the killing element impact. Although many previous studies have been carried out, the complexity of the interaction between the projectile and the target and the diversity of the damage forms of the protective materials make the existing research results difficult to meet the requirements of various kinds of killing elements for the assessment of injury effects.

Terrorist activities have the characteristics of concealment, abruptness and timeliness. Sniper rifle is the first time choice weapon for precise shooting in anti-terrorism. High-precision sniper bullets mostly adopt the lead core structure of front closing. This kind of sniper bullets can penetrate into the soft protection at high speed and for direct injury to the personnel, but it is difficult to realize the breakdown of the soft protection at low speed. At this time, it will produce the blunt effect, even if the blunt damage can not cause permanent disability, but the instantaneous disability and short-term disability of the personnel in the battlefield and counter-terrorism that still play a positive role in the activities. In this paper, the experiment and numerical simulation of small caliber sniper projectile penetrating gelatin with soft protection target are carried out. By comparing the numerical simulation results of the experiment, the reliability of the material model and calculation method of the simulation is verified, and energy dissipation law of sniper projectile under the condition of non-penetration is studied. The study of trauma ballistics shows that energy transfer is at the root of trauma. It is of practical significance to study the energy dissipation law of soft protective gelatin impacted by sniper projectile, for the damage characteristics and mechanism of BABT, the design of sniper projectile and the development of new bulletproof materials.

2. Test conditions and methods

In this paper, the initial velocity of a projectile is controlled by controlling the charging quality to simulate the soft protective effect of penetration at different distances. A small caliber lead core structure sniper bullet is used in the test. According to the viscoelastic characteristics of gelatin and the similarity with the biological soft tissue, gelatin with the concentration ratio of 4 °C, 10% and the size of 300 mm * 300 mm * 300 mm is used as the target, in which gelatin is attached with soft body armor(soft fiber layer). The soft fiber layer is composed of 46 layers of UHMWPE fiber. Each layer is 0.2mm thick, and the soft fiber layer size is 300mm * 300mm * 9.2mm.

Figure 1 and figure 2 are the layout diagram and field diagram of the test device respectively. The target is placed at a distance of 20m from the muzzle, and speed measuring device is placed in front of the target. The impact velocity of the projectile before penetrating into the soft fiber layer is obtained by the velocity measuring device. When the projectile passes through the second target of the velocity measuring target, it triggers the high-speed camera to take photos, and to capture the deformation images of gelatin and soft fiber layer after the projectile hitting the soft fiber layer. Through the information processing of the high-speed photographic image, the deformation images of gelatin and the soft fiber layer are obtained. First, the ultimate penetration velocity of projectile penetrating soft fiber layer is obtained by experiment, and then the projectile under this velocity is tested for impact soft fiber layer.

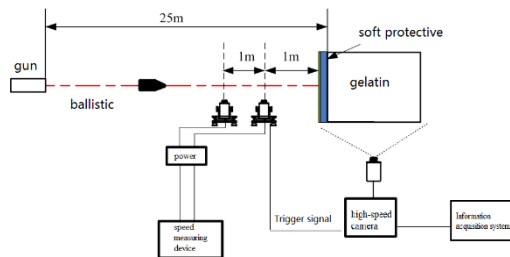


Figure 1. Test device layout diagram.

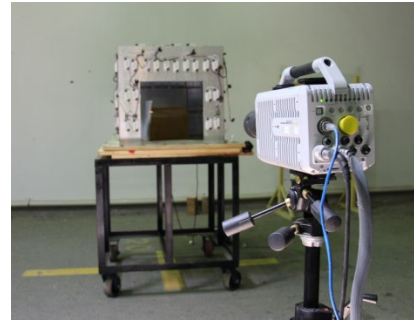


Figure 2. The scene graph of test device.

3. Numerical simulation model

3.1. Calculation model

The finite element model of interaction between projectile and soft protective gelatin is established (as showed in figure 3). The projectile is composed of two parts: brass jacket and lead core. The projectile impacts soft fiber layer of penetration angle α and velocity of v , v is parallel to the axis of the projectile, α is 0° , 5° , 10° , 15° , 20° , 25° and 30° respectively, ignoring the influence of the penetration angle. The soft fiber layer used in the simulation is modeled according to the actual size. Because the soft protective under non-penetrating penetration is mainly studied in this paper, in order to improve the calculation efficiency, the size of gelatin is a cuboid of $300\text{mm} \times 300\text{mm} \times 100\text{mm}$. The soft fiber layer was used a denser grid in the area where projectile acted, the size is the same as that of the projectile grid, and the relatively sparse grid is used in the part of gelatin far away from the acting area, such as this can speed up the calculation efficiency and improve the resource utilization rate on the premise of ensuring the calculation accuracy. Erosion contact is defined between soft fiber layer and projectile, automatic surface to surface contact is defined between soft fiber layer and gelatin, also projectile jacket and lead core, then automatic single surface contact is defined for soft fiber layer.

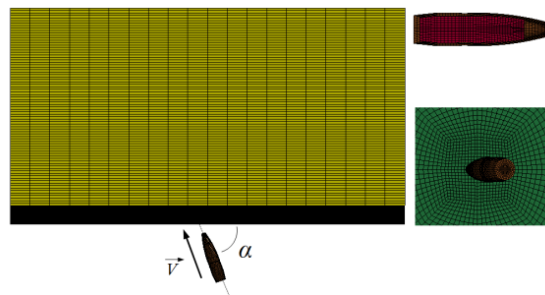


Figure 3. Finite element mesh of projectile and soft protective gelatin.

3.2. Constitutive model and parameters

Johnson-Cook material model is suitable for describing the constitutive relationship of materials under the conditions of large deformation, high strain rate and high temperature. It is widely used in the numerical calculation of ballistic penetration impact and metal explosive forming [8]. The damage of the material is defined as:

$$D = \sum \Delta \bar{\epsilon}^p / \epsilon^f$$

Initially, $D=0$, when $D=1$, the material failed. Among them, $\Delta \bar{\epsilon}^p$ is the plastic strain increment of a time step, and ϵ^f is the failure strain with stress state, strain rate and temperature of current time step. The failure strain ϵ^f is expressed as:

$$\epsilon^f = (D_1 + D_2 \exp D_3 \sigma^*) (1 + D_4 \ln \dot{\epsilon}^*) (1 + D_5 T^*)$$

Where, $D1 \sim D5$ are material constants. Therefore, Johnson-cook material model and Grunisen equation are used to express the constitutive relationship of each material of projectile when considering deformation. The material parameters of each part of projectile are shown in table 1 and table 2.

The soft fiber layer of UHMWPE can better reflect the performance of the fiber by selecting MAT_LAMINATED_COMPOSITE_FABRIC material model. The relevant physical properties of UHMWPE soft fiber layer are listed in table 3.

Gelatin is a kind of polymer material, which has rheological properties under certain pressure. Therefore, it is described by the fluid elastic-plastic material model (MAT-ELASTIC_PLASTIC_HYDRO) combined with the linear equation of state (LINEAR_POLYNOMIAL). The constitutive parameters are shown in table 4.

Table 1. Mechanical properties of material of bullet.

material	$\rho/(\text{g/cm}^3)$	E/GPa	ν	A/MPa	B/MPa	N	C	m	Tr/K	Tm/K
jacket	8.52	115	0.31	206	505	0.42	0.01	1.68	293	1189
core	10.66	1	0.42	24	300	1	0.1	1	293	760

Table 2. The equation of state properties of bullet [10,11].

material	C/(m/s)	S1	γ_0
jacket	3834	1.429	2.0
core	2028	1.627	2.253

Table 3. Mechanical properties of material of gelatin [7].

material	$\rho/(\text{g/cm}^3)$	Ea/GPa	Eb/ GPa	ν
UHMWPE	0.97	80	30	0.2

Table 4. Mechanical properties of material of gelatin [8,9].

material	$\rho/(\text{g/cm}^3)$	G/GPa	SIGY/ GPa	C0/ GPa	C1/ GPa	C2/ GPa	C3/ GPa
gelatin	1.03	2.83E-4	2.64E-4	0	2.38	7.14	11.9

3.3. Verification of numerical calculation results

Generally, the consistency between the numerical calculation results and the experimental results is determined by comparing the number of penetration layers and the deformation of the gelatin. This paper takes the projectile with 475m/s impact the soft fiber layer as an example to illustrate. Figure 4 shows the comparison between the numerical simulation results and experimental results taken by high-speed photography of the shape process of the inner bulge of gelatin under 475m/s projectile. Table 5 shows the comparison of test and simulation results.

Table 5. Comparison between simulation results and test results.

simulation Velocity (m/s)	experimental Velocity (m/s)	experimental number of penetration layers	simulation number of penetration layers
430	428	24	23
475	475	27	25
490	491	30	27
580	584	31	42
580	599	42	42

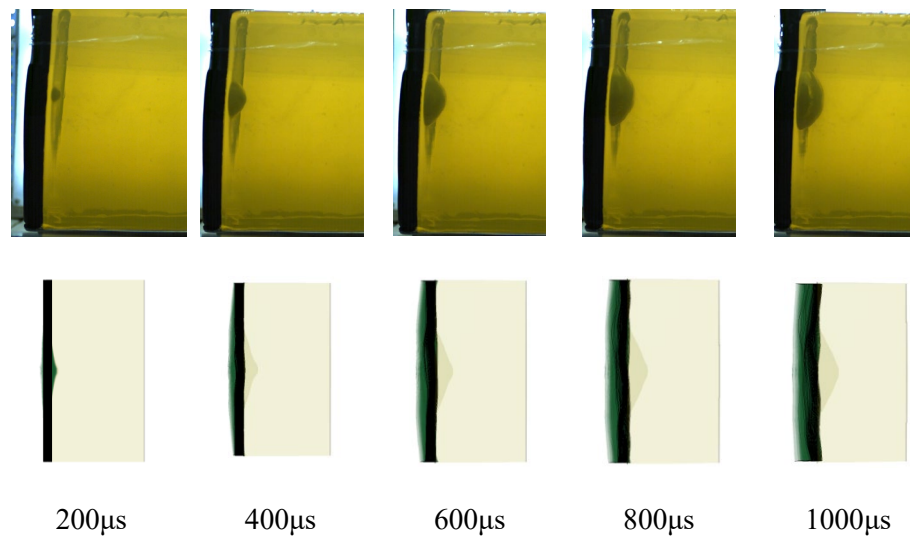


Figure 4. The comparison between numerical results and test results.

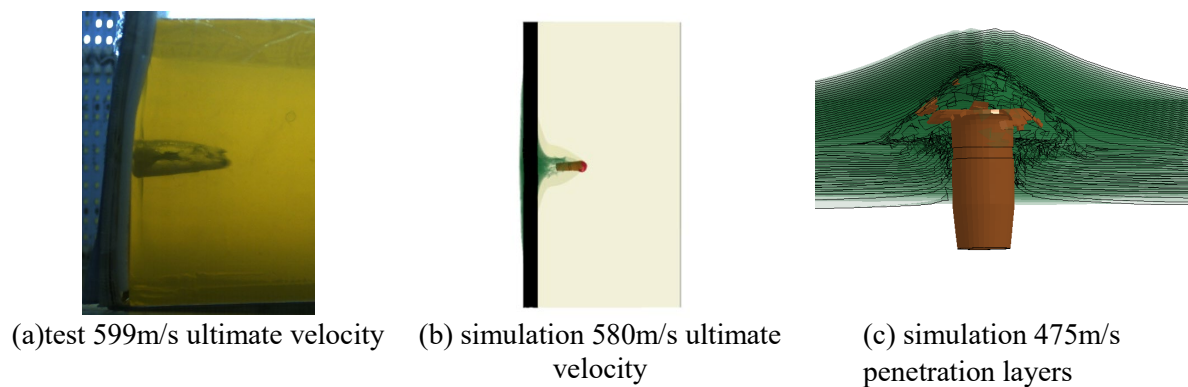


Figure 5. Comparison of simulation and test penetration.

Through comparison, it can be found that the main phenomena of numerical simulation results and high-speed photography experimental results are basically the same, which shows that the numerical calculation model and the numerical method adopted in this paper have high accuracy, and the numerical results can better reproduce the movement of projectile in the soft fiber layer. Therefore, the feasibility of material model and calculation method is proved, and the simulation has good reliability.

The comparison between the numerical simulation results and the experimental recovery results of projectile deformation is shown in figure 6. The results show that in the simulation, except for the large bending deformation of the arc part of the projectile, the bottom part of the projectile is basically consistent with the experimental results, which is due to the Lagrange algorithm based on the erosion algorithm used in the simulation, and the mesh of the projectile is deleted during the penetration process.

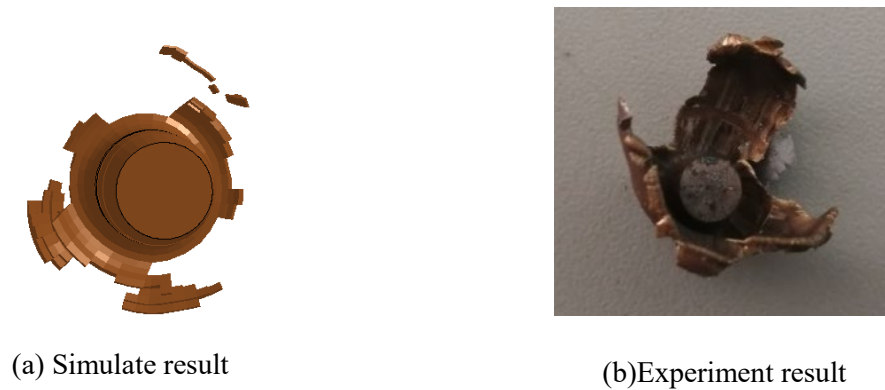


Figure 6. Comparison of bullet fracture between simulation and experiment results.

4. Simulation results and analysis

Based on the above material model, the numerical simulation of the projectile penetrating soft fiber layer(UHMWPE) was carried out. The impact velocity of projectile selected in the simulation is 430, 475 and 490m/s.

4.1. Stress analysis at typical time

Figure 7 shows stress diagram of the numerical simulation results of the projectile and soft fiber layer at several typical time during the penetration process of 475m/s projectile impacted soft fiber layer. From figure 7, it shows the stress situation of soft fiber layer and projectile deformation.

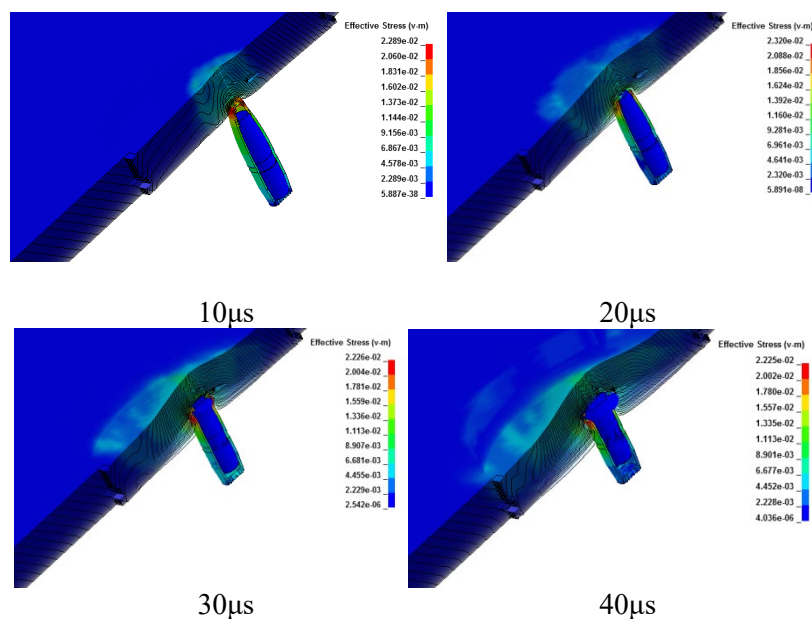


Figure 7. Mises stress cloud diagram.

In the process of penetration, the stress of lead core is obviously smaller than that of the jacket. For the lead core, the stress near the tip is larger, and the stress is smaller when it is far away from the tip, which is mainly due to the deformation of the jacket from the tip, so that the stress of the lead core closest to the tip is squeezed and increased. At the same time, the stress wave is produced when the projectile impacted the fiber layer. It can be seen from figure 7 that the stress wave propagates in two directions. One is that the stress wave propagates along the axial direction of the fiber layer, and the stress wave continuously reflects on the interface between the layers and the free surface of the fiber

layer. The other direction is the plane of the fiber layer. The stress wave propagates along the fiber with continuous pulses. Through the interaction between the fibers, the stress wave expands on the fiber, and the energy is absorbed in a certain area.

When the projectile contacts the fiber layer at a very high speed, the fiber is squeezed and sheared by the projectile. When the shear stress of the fiber is greater than its limit, the fiber is sheared and destroyed, and the projectile is also upsetting due to the front stress by plastic deformation beyond the elastic limit, because the obstruction of the fiber. When the contact area between the deformed projectile and the fiber layer becomes larger, the number of fibers involved in preventing the projectile from moving forward increases, the velocity of the projectile further decreases, the impact kinetic energy decreases, the fibers are further stretched, and the kinetic energy of the projectile is continuously absorbed. When the tensile limit of the fibers is exceeded, the fiber dimension is stretched and destroyed. Therefore, it can be seen from the numerical simulation that the main failure mode of the fiber in the early stage of penetration is shear failure. While in the later stage is a tensile failure.

At the later stage of penetration, the deformation of projectile becomes more and more obvious, the shape of projectile is similar to petal shape, the jacket of projectile is seriously damaged, and the kinetic energy is further converted into the deformation energy of projectile itself and the elastic potential energy of fiber until the projectile no longer moves forward. The stress wave continues to propagate between the fibers, and obvious "back convex" phenomenon occurs at the back of soft fiber layer. Then the elastic potential energy accumulated in the fiber begins to release, the fiber rebounds, the projectile is bounced back, and the projectile appears reverse velocity.

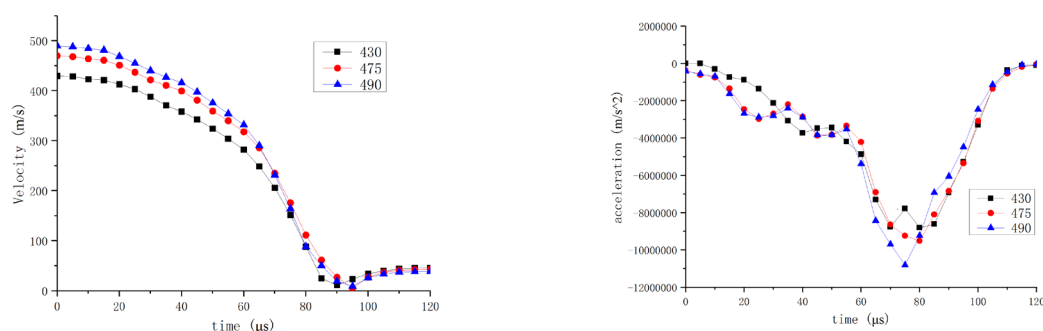


Figure 8. Velocity change curve and acceleration change curve of projectile.

Figure 8 shows the velocity curve and acceleration curve of projectile. Through the observation of the velocity time history and acceleration time history of penetration of projectile into soft fiber layer, it can be found that the velocity of projectile first decreases obviously, and then returns to gentle. However, the absolute value of acceleration rises rapidly from 0 to 80 μs , and then returns to zero after the decay from 80 μs to 120 μs .

In the early stage of penetration, from the time projectile began to contact with the soft fiber layer continued to 40 μs , in this stage, because of the rapid impact of the projectile, the front part of the fiber layer began to be sheared and damaged. The remaining layers were squeezed by the projectile, and the layer to layer squeezed more tightly. At the same time, because of the deformation of the projectile and the increasing number of fibers involved in preventing the projectile from moving forward, the projectile was subjected to fibers and the resistance of the layer rises rapidly.

In the middle stage of penetration, with the continuous penetration of the projectile, the number of fibers damaged by shear and tension is increasing, and the damaged fiber layer in the front no longer has an obstacle effect on the projectile. At the same time, the velocity of the projectile is much smaller than the initial time, which makes the resistance of the projectile begin to decline, the acceleration begins to decline, and the velocity of the projectile further decline.

In the later stage of penetration, the penetration speed velocity of the projectile continues to decline, and the obstruction of the projectile by the soft fiber layer is further reduced, which is highlighted by the fact that the reverse acceleration of the projectile continues to decline and tends to zero. At the same

time, the elastic potential energy stored in the fiber layer in the earlier stage starts to release, and the fiber begins to rebound, which makes the projectile rebound, with a small amount of reverse speed.

4.2. Analysis of energy conversion at different speeds

According to the analysis of velocity time history of the projectile in 4.1, the projectile begins to rebound at about 100 μ s, so the energy analysis of 0-120 μ s in the whole simulation time history is selected in this paper. Analyzing the energy change in the numerical simulation under the condition of projectile normal penetration, through the numerical simulation, the energy conversion of projectile in the process of penetrating the soft fiber layer can be obtained. The energy change curve of projectile(E_{prj}) and gelatin(E_{gel}) is shown in figure 9.

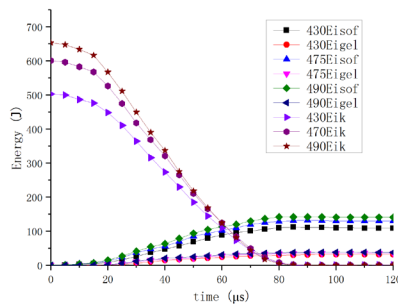


Figure 9. Energy changes of projectile and gelatins.

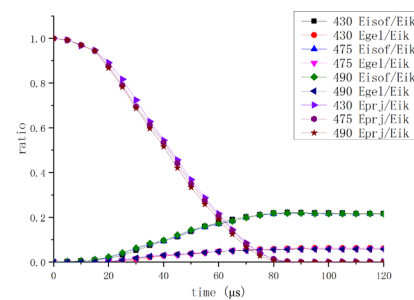


Figure 10. Curve of the energy ratio.

The process of projectile penetrating into gelatin target with soft fiber layer protection is also the process of energy conversion. The initial energy of the whole system is the kinetic energy of the projectile. In the process of penetration, the projectile, soft fiber layer and gelatin are deformed or damaged in varying degrees. These deformation energy and the energy taken away by projectile fragments are all derived from the transformation of projectile kinetic energy.

In the process of projectile penetrating soft protective gelatin, because of the deformation of projectile and the deformation and destruction of fiber, the initial kinetic energy of projectile is not only transformed into its own denaturation energy and internal energy, but also into the internal energy of fiber, part of which is transferred to gelatin with the fiber. The time-dependent curve of the energy ratio of projectile kinetic energy(E_k), soft fiber layer(E_{isof}), gelatin(E_{igel}) and the initial kinetic energy(E_{ik}) is showed in figure 10. When the projectile starts to penetrate the soft fiber layer, the internal energy of soft fiber layer(E_{isof}) increases. This is because in this process, the velocity of projectile decreases and the projectile itself is seriously deformed, which is converted into its own deformation energy. The kinetic energy of the projectile is largely converted into the internal energy of the fiber layer, and then the internal energy of the projectile, with the penetration in-depth, is further converted into the internal energy of fiber and its own deformation energy and internal energy, until the penetration direction of the velocity of projectile is zero. Then, due to the release of elastic potential energy accumulated on the fiber, the fiber begins to rebound, the projectile is bounced back, and the internal energy of the fiber is correspondingly reduced. Therefore, from figure 10, it can be seen that the internal energy of the soft fiber layer reaches the maximum value and then slightly decreases and then tends to be stable.

The energy of gelatin begins to rise in this process, which is mainly due to the deformation of soft fiber layer and the propagation of a stress wave, resulting in the deformation energy gathered due to the sunken of the impact area of gelatin. From figure 9 and figure 10, it can be seen that the maximum energy of gelatin is 31.4J, 35.7J and 38.2J at the velocity of 430, 475 and 490, respectively, while the amount percentage of the energy of gelatin accounts for the initial total energy of projectile is 6.25, 5.97 and 5.84% respectively. It can be seen that adding UHMWPE soft protection in front of gelatin target can effectively reduce the conversion of projectile energy to gelatin and achieve the defense effect.

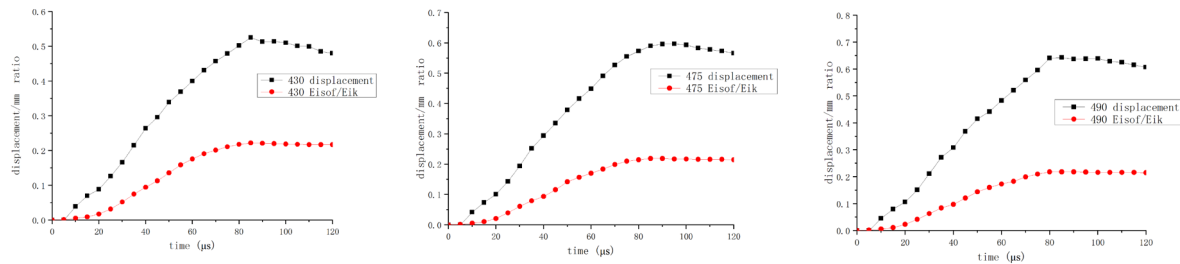


Figure 11. Curve of soft protective maximum displacement and E_{isof}/E_{ik} at different speeds.

At about 80 μs, the soft protective begins to rebound when the displacement reaches the maximum value, and the soft protective no longer absorbs energy after the displacement rebound. From the perspective of displacement change, when the velocity of projectile increases, the soft protection needs more deformation to unload the projectile energy. From the values of kinetic energy / initial kinetic energy values of projectile (E_k/E_{ik}), soft protection absorbing energy / initial kinetic energy (E_{isof}/E_{ik}) and gelatin absorbing energy / initial kinetic energy (E_{igel}/E_{ik}), most of the kinetic energy of projectile is absorbed by its own broken deformation energy in the process of penetration, so soft protection mainly relies on high strength to crush projectile and unload the impact kinetic energy in the process of anti lead core structure rifle bullet.

4.3. Analysis of energy conversion at different penetration angle

In this paper, the credibility of the numerical model of projectile penetrating soft protective gelatin under the condition of normal penetration is verified. The simulation of soft protection impacted by a projectile under different penetration angle is carried out to study the influence of different penetration angle on the energy absorption of soft protection and gelatin.

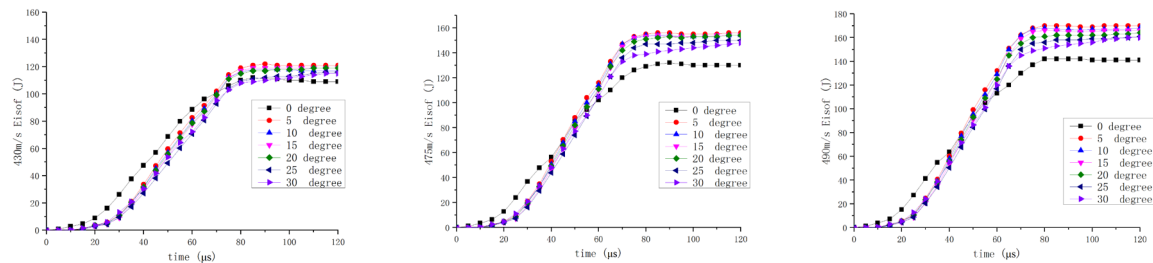


Figure 12. Curves of E_{isof} – time at different penetration angle at different velocities.

Figure 12 shows the energy absorption-time curve of soft protection under different velocity at different penetration angle with the interval of 5 degrees at 0-30 degrees. It can be seen from the curve that the energy absorption of soft protection increases with the increase of the penetration angle, and the energy absorption of soft protection is the minimum under the condition of normal penetration. It can be said that the UHMWPE soft protection stray projectile has a more significant defense effect than the normal penetration.

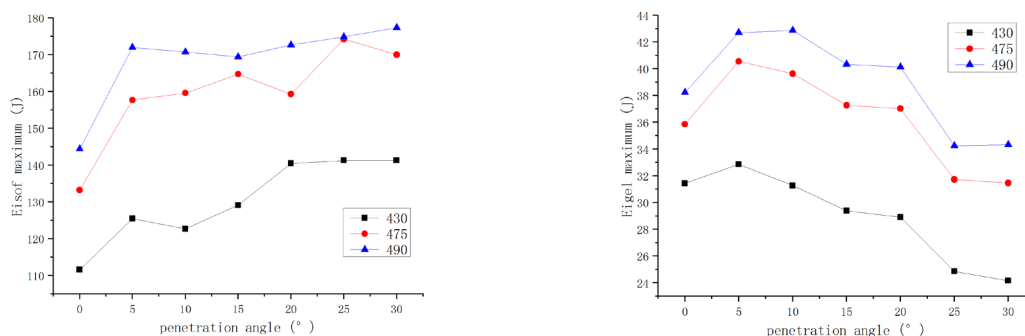


Figure 13. Relation between maximum soft protective energy and maximum gelatin energy and penetration angle.

It can be seen from the graph of the relationship between the maximum value of the soft protective energy absorption and the penetration angle and the graph of the relationship between the maximum value of the gelatin energy absorption and the penetration angle (figure 13) that with the increase of the incidence angle penetration angle, the soft protective energy absorption increases and the gelatin energy absorption decreases.

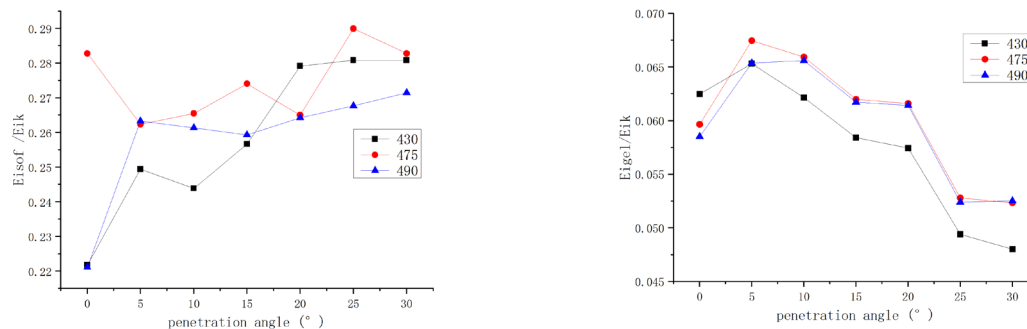


Figure 14. Relationship between maximum/initial energy of soft protection and maximum/initial kinetic energy of gelatin and penetration angle.

Figure 15 shows the curve of energy change and the ratio of kinetic energy (E_k) and internal energy (E_{in}) to initial kinetic energy (E_{ik}) with penetration angle. The larger the penetration angle is, the larger the internal energy of the projectile will be when the soft protection starts to rebound, and the smaller the energy of the soft protection will be. However, the larger the ratio of the soft protection energy absorption to initial kinetic energy (E_{isof}/E_{ik}) is, also the larger the penetration angle is, and the closer the value of the ratio of the soft protection energy absorption to initial kinetic energy is at different speeds. The energy (E_{igel}) and energy absorption ratio of gelatin (E_{igel}/E_{ik}) decreased with the increase of the penetration angle.

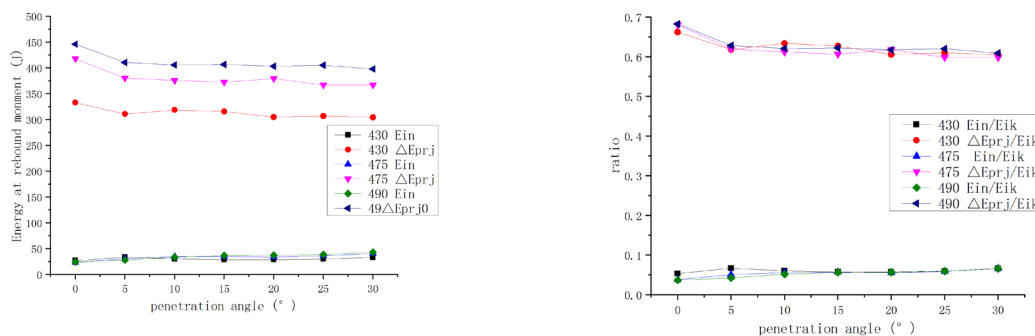


Figure 15. The relationship between E_{prj} 、 E_k/E_{ik} 、 E_{in}/E_{ik} of the projectile with t penetration angle.

From the general trend, with the increase of penetration velocity, the initial energy of the projectile does not change at the same velocity, and the energy dissipation by the projectile during the penetration process also increases; the ratio of the initial kinetic energy of the projectile to the soft protective energy increases with the increase of penetration angle. After the soft protection absorbs the energy of the projectile, the percentage of energy obtained by gelatin in the total energy increases with the penetration velocity increase and decrease.

5. Conclusion

In this paper, a finite element model of one small - diameter lead - core construction sniper bullet impact with soft protective gelatin was established. By comparing with the typical physical phenomena of experimental data, the validity, accuracy and credibility of the model were verified. Based on the numerical simulation results, the energy conversion analysis is carried out, and the following conclusions are obtained:

1) The failure of UHMWPE soft fiber layer is mainly caused by shear and tensile failure, which is carried out with projectile penetration, first shear and then tensile failure, and the energy absorption of soft fiber layer increases with the penetration depth.

2) the fracture of projectile structure is the main reason of energy dissipation, and nearly half of energy is dissipated in the process of penetration.

3) Under the condition of normal penetration, the energy absorption of soft protection and gelatin increases with the increase of penetration velocity, and the energy percentage of gelatin in the initial total energy of the projectile decreases with the increase of initial velocity.

4) The larger the penetration angle, the closer the value of E_{isof}/E_{ik} at different velocity. The energy of gelatin and the ratio of gelatin energy absorption decrease with the increase of the penetration angle. With the increase of penetration velocity, the energy dissipated by the projectile during the penetration process also increases. The ratio of soft protective energy absorption increases with the increase of the penetration angle, and the ratio of gelatin energy absorption increases with the increase of penetration velocity and reduce.

Acknowledgment

The authors would like to thank the Science and Technology on Transient Impact Laboratory, Beijing, for their financial support.

References

- [1] Wang Lingqing. 2013 *The behind armor blunt trauma and biomechanical characteristics after different rifle bullets impacting the swine's armor vest* (Chongqing: Third Military Medical University (in Chinese))
- [2] Wang Xinyi. 2017 *Study on energy dissipation during blunt impact of helmet* (.Nanjing: Nanjing University of Science and Technology (in Chinese))
- [3] H L Gower and D S Cromon 2008 *Int J Impact Eng* **35** 1000—08
- [4] H L Gower and D S Cromon, A Plumtree. Ballistic impact response of Laminated composite panels Xia Qingbo, Yan Luhui and Feng Xingmin. 2011 Numerical simulation of elastic penetration resistance of soft fiber layer *Journal of sichuan military engineering* (2) 119-21 (in Chinese)
- [5] Nail N K, Shrirao P and Reddy B C K. 2006 *International Journal of Impact Engineering* **32**(9) 1521-52
- [6] Huang Gongwu, Chen Aijun and Luo Shaomin, et al. 2013 *Computer simulation* **30**(10) 6-9 212. (in Chinese)
- [7] Liu Kun, Wu Zhilin and Ning Jianguo et al. 2018 *Acta Armamentarii* **39**(1) 1-17 (in Chinese)
- [8] Liu Kun, Wu Zhilin and Xu Wanhe et al. 2012 *Explosion and Shock Waves* **32**(6) 616-22 (in Chinese)
- [9] WEN Yao-ke, XU Cheng and CHEN Ai-jun, et al. 2013 *ACTA Armamentarii* **34**(1) 14-9 (in Chinese)
- [10] Yaoke Wen and hen Xu, et al. 2013 *International Journal of Impact Engineering*. **62** 142-51.