Research Article

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Investigation on the anti-penetration performance of the steel/nylon sandwich plate

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Abstract: In this paper, a new method is developed to investigate the anti-penetration performance of the steel/nylon sandwich plate, which incorporates experimental method with numerical simulation. Constitutive parameters of the steel/nylon sandwich plate are measured by the Hopkinson Pressure Bar, and LS-DYNA is applied to simulate the penetration process of projectiles into the sandwich plate. The dynamic response, failure modes and energy absorption coefficients are obtained, and the penetration tests are conducted to verify the numerical method. Results show: results obtained by experimental and numerical methods have very high agreement, which demonstrates that the method proposed can be applicable for predicting the anti-penetration performance of the sandwich plate.

Keywords: Sandwich plate; Steel/nylon; Anti-penetration; Energy absorption coefficient

1 Introduction

With the excellent performance of light-weight, high stiffness and high energy absorption capability, sandwich plates have been more and more widely used in protective structures recently. A sandwich plate may be defined as a composite component, which features a light-weight core material between two relatively thin high-strength face-sheets [1, 2]. In order to promote the application of sandwich plates in different protective equipments, it is necessary to investigate mechanical properties and anti-

penetration performance of sandwich plates with different cores.

In recent years, the application prospect of sandwich plates has been very broad, and scholars have carried out the analysis of mechanical and anti-penetration performance of sandwich plates by static and impact experiments. W K Shih and B Z Jang [3] studied the damage patterns of sandwich plate impacted by a normal object with low velocity and high energy in the test, and found that the influence of the core on the anti-penetration performance was really limit. W Goldsmith, *et al.* [4] investigated the perforation damage behavior of the composite sandwich plate with the honeycomb core, which was impacted by spherical, cone and flat nose projectile, and the results demonstrated that the thickness of face-sheet played an important role in anti-penetration performance. W J Niu, F Yang, *et al.* [5] conducted the penetration experiments for the clamped quadrate sandwich plate which was consisted of aluminum foam core, and investigated the anti-penetration performance of the sandwich plate. M Aydin, M K Apalak, *et al.* [6] used a 9.0 mm parabellum projectile to impact the functionally graded sandwich plate, and studied the ballistics performance by the experimental method. M Zhang, H Zhao, *et al.* [7] designed the high velocity impact experiment of aluminum foam sandwich plates, and used the Hopkinson Pressure Bar to investigate the penetration resistance of sandwich plates. K Guo, L Zhu, *et al.* [8] used the INSTRON 9350 Drop Tower to conduct the impact experiment of aluminum foam sandwich plates, and analyzed the anti-penetration performance of the sandwich plates. The experimental method to investigate the anti-penetration performance of the sandwich plate can obtain the results intuitively and has high credibility, but the cost of the experiment is really high, and the process is really complicated.

In addition to experimental methods, scholars have also proposed several numerical methods or numerical-experimental methods to investigate the anti-penetration performance of sandwich plates based on the finite element software. M Meo *et al.* [9] used the LS-DYNA finite element code to predict the threshold of impact damage and delamination initiation of sandwich plates. G Y Hang, W L Yu, *et*

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al. [10] investigated the anti-penetration performance of different sandwich plates by the LS-DYNA. C Y Ni, F Jin and T J Lu [11] adopted the LS-DYNA to evaluate the ballistic performance of the ultra-light pyramidal lattice sandwich plates. J Yu [12] simulated the process of the projectile into concrete targets by the ANSYS/LS-DYNA3D, and studied the anti-penetration ability of the shelter plate made of steel structure of the steel fiber concrete. G Y Huang, W L Yu, *et al.* [13] established the mesh model of the bullet and sandwich plate, and applied LS-DYNA to analyze the dynamic response of the bullet and the anti-penetration performance of the sandwich plate. F Yang, W J Niu, *et al.* [14] used the LS-DYNA to establish the finite element model of the sandwich plate, and investigated the influence of face-sheet and core thickness on the anti-penetration performance of the sandwich plate. E Carrera, S Valvano, *et al.* [15] developed the advanced finite shell elements to establish the mesh model of composite laminated shell structures, and conducted the linear static stress analysis by the numerical method. A Pagani, S Valvano, *et al.* [16] proposed the variable-kinematic model to complete the implementation of structures, and investigated the static characteristics of the sandwich plates by the finite element method. S K Kumar, D Harursamath, *et al.* [17] applied the variable through-the-thickness kinematic shell to establish the mesh model of composite shell structures, and conducted the modal analysis by finite element method. G Bi, J Yin, *et al.* [18] investigated the anti-penetration of single-layer honeycomb sandwich structures, and concluded that the honeycomb diameter affected the penetration resistance of the sandwich plates. Q Q Liu, S P Wang, *et al.* [19] developed a numerical method to analyze the penetration resistance of the polyurea-core sandwich plate by the AUTODYN-2D axisymmetric algorithm, and verified the correctness of this numerical method by experiments. N Zhao, R Ye, *et al.* [20] took the sandwich plates with steel face-sheet and aluminum foam core as the research object, and investigated the penetration and deformation mechanism of sandwich plates under different penetration speeds by the experimental and numerical method. The numerical method was used to investigate the anti-penetration performance of sandwich plates, which was simple and time-consuming, but the agreement with experimental results was not high. Therefore, the accuracy of the numerical method still needed further verification.

In order to overcome shortcomings of the existing experimental and numerical methods, a method incorporating experimental approach with numerical simulation is developed to analyze the anti-penetration performance of steel/nylon sandwich plates. A universal testing machine and Hopkinson Pressure Bar are used to measure the constitutive parameters of the steel and the nylon, and these val-

ues are given to corresponding materials in the numerical simulation process. The anti-penetration performance of sandwich plates is investigated by the experimental method and the numerical simulation method, and the feasibility of the method proposed in this paper is to be verified by a comparison between numerical and experimental results.

2 Experimental procedure

2.1 Specimens and Projectiles

In this paper, a square sandwich plate is taken as the research object, which consists of a nylon core and two steel face-sheets. The face-sheets are made of A3 steel with different thickness (0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm), and the size of the face-sheets is 200 mm × 200 mm. The density of the nylon 6 core is 1040 kg/m³, and the thickness of the core is 30 mm. The nylon core and two steel face-sheets are glued together by the epoxy resin, and the sandwich plate is fabricated.

The typical quasi-static tensile stress-strain curve of the nylon is presented in Figure 1. It is well known that, for polymer matrix composites, strain rate greatly influences their dynamic behavior. With Hopkinson Pressure Bar, the dynamic compression stress-strain curve of the nylon is presented in Figure 2. As shown in Figure 2, we can see that the yield strength of nylon gradually increases as the strain rate increases.

The projectile material is steel, and two different shapes of projectiles are designed as shown in Figure 3, shaped as a blunt nose and a hemisphere nose. The size of projectiles is shown in Figure 3: the diameter and height of the steel projectiles is 8.8 mm and 20 mm respectively, and the approximate masses of the steel projectiles are $6.8^{+0.15}_{-0.15}$ g. Mechanical properties of face-sheets, the nylon and the projectile, obtained from standard quasi-static tests, are illustrated in Table 1.

Figure 1: True stress-strain curve of nylon

Table 1: Mechanical properties of the projectile, the face-sheet and the nylon

Component part	Material	Density (kg/m ³)	Young's modulus (GPa)	Poisson's ratio	Yield strength (MPa)
Projectile	Die steel	7800	206	0.29	450
Face-sheet	A3	7800	206	0.29	240
Nylon core	PA6	1140	3.3	0.41	60

Figure 2: Stress-Strain curve of nylon in different strain rate **Figure 3:** Dimensions of projectiles

2.2 Experimental set-up

Penetration tests are conducted by the air gun system as shown in Figure 4, and the internal diameter of the barrel is 25 mm. A special nylon sabot with the diameter of 8.15 mm is used to hold the steel projectile during the experiment, as shown in Figure 5. To avoid the effect of the nylon sabot on the experiment results, a special device is employed to remove the sabot before the impacts are exerted on the specimen, as shown in Figure 6. A high speed camera is placed at the side of the specimen, and used to measure the initial impact velocity and the motion trajectory of the projectile. The peripheral regions of the specimens are fully clamped by 8 bolts, leaving an exposed area of 120 mm × 120 mm.

According to different geometric configurations, 18 sandwich plates are made, which will be applied to the penetration tests by the air gun system. In order to investigate effect of the face-sheet thickness, the shape of projectiles and the initial velocity on the anti-penetration performance, 18 steel/nylon sandwich plates will be classified into three groups. Geometric parameters of 18 sandwich plates are listed in Table 2.

Table 2: Geometric parameters of 18 sandwich plates

Number	SP1-1	SP1-2	SP1-3	SP1-4	SP1-5	SP2-1	SP2-2
t_A (mm)	0.50	0.49	0.50	0.50	0.50	0.90	0.89
t_B (mm)	30.59	30.60	30.53	30.57	30.63	30.59	30.48
t_C (mm)	0.50	0.50	0.50	0.50	0.49	0.88	0.90
Number	SP2-3	SP2-4	SP2-5	SP3-1	SP3-2	SP3-3	SP3-4
t_A (mm)	0.86	0.90	0.90	1.38	1.39	1.37	1.37
t_B (mm)	30.61	30.60	30.54	30.55	30.56	30.48	30.63
t_C (mm)	0.89	0.88	0.90	1.38	1.39	1.38	1.37
Number	SP4-1	SP4-2	SP4-3	SP4-4			
t_A (mm)	1.77	1.77	1.76	1.76			
t_B (mm)	30.64	30.63	30.36	30.62			
t_C (mm)	1.77	1.77	1.77	1.77

Figure 4: Sketch of experiment set-up

Figure 5: Dimension of sabot

Figure 6: Projectile sabot removal device

(a) blunt-nosed projectile

(b) hemispherical-nosed projectiles

Figure 7: Failure patterns of sandwich plates obliquely impacted by projectiles

3 Experimental results

3.1 Failure modes

In penetration tests, the impact energy determines the failure mode of sandwich specimens, and different failure modes are shown in Figure 7. Sometimes the pressure of the air gun is not big enough, steel/nylon sandwich plates will not be fully penetrated by projectiles, and only a hole will be left in the sandwich specimens.

As shown in Figure 7(a, b), both blunt-nosed hemispherical-nosed projectiles cannot penetrate the sandwich plates. Circular holes can be obviously observed in the front face-sheet and the nylon core, but the back face-sheet is not intact. At the same time, the hole of sandwich plate penetrated by blunt-nosed projectile is smooth, it can be concluded that the sandwich plate penetrated by hemispherical-nosed projectile is rough.

Table 3: Experiential results of sandwich plates by projectiles

Serial number	Types of projectiles	Mass of projectiles (g)	Mass of sabot projectiles (g)	Initial velocity of projectiles ($\text{m}\cdot\text{s}^{-1}$)	Penetration results
SP1-1	blunt	6.84	8.21	–	ballistic deviation
SP1-2	blunt	6.83	8.15	252.40	penetration depth: 5.65 mm
SP1-3	blunt	6.82	8.20	215.84	penetration depth: 3.63 mm
SP1-4	hemisphere	6.78	8.15	250.53	penetration depth: 7.01 mm
SP1-5	hemisphere	6.79	8.16	217.39	penetration depth: 6.42 mm
SP2-1	blunt	6.80	8.20	247.90	penetration depth: 3.97 mm
SP2-2	blunt	6.82	8.12	219.91	penetration depth: 2.78 mm
SP2-3	blunt	6.77	8.15	–	ballistic deviation
SP2-4	hemisphere	6.78	8.19	242.38	penetration depth: 5.39 mm
SP2-5	hemisphere	6.79	8.10	216.11	penetration depth: 4.02 mm
SP3-1	blunt	6.82	8.20	256.45	penetration depth: 3.36 mm
SP3-2	blunt	6.76	8.23	–	ballistic deviation
SP3-3	hemisphere	6.78	8.22	–	ballistic deviation
SP3-4	hemisphere	6.77	8.18	251.47	penetration depth: 4.40 mm
SP4-1	blunt	6.80	8.18	244.27	penetration depth: 3.10 mm
SP4-2	blunt	6.69	8.12	–	ballistic deviation
SP4-3	hemisphere	6.75	8.18	–	ballistic deviation
SP4-4	hemisphere	6.78	8.15	–	ballistic deviation

3.2 Quantitative results

In the penetration tests, the penetration depth is also an important parameter for anti-penetration performance of sandwich plates. For 18 sandwich plates above, penetration depths of projectiles are collected during the tests, which are listed in Table 3.

As shown in Table 3, it can be concluded that the shape of the projectile, initial velocity and the thickness of face-sheet are all important factors of the penetration depth.

Figure 8: Finite element model of steel/nylon sandwich plate

4 FE MODEL

4.1 Modeling Geometry

The LS-DYNA is used to build 3D model and finite element model of steel/nylon sandwich plates. Considering the symmetry of the projectile and the sandwich plate, only a quarter of the projectile and plate with symmetric boundaries are modeled in this paper, as shown in Figure 8.

To improve the computational efficiency, the central area is meshed by the mesh size: $0.5 \text{ mm} \times 0.5 \text{ mm}$, while the other area is meshed by the mesh size: $2.0 \text{ mm} \times 2.0 \text{ mm}$. The bolts, which are used to clamp sandwich plates to the fixture in the experiment, are represented by nodal constraints in numerical models. Two steel face-sheets and

nylon core are all modeled by solid elements, and the blunt-nosed projectile and hemispherical-nosed projectile are also modeled by solid elements. The surface-to-surface contact option of eroding is used between the projectile and sandwich plate.

4.2 Material Model

The projectile made of A5 steel were represented by material 20 (*MAT_RIGID), the face sheet made of A3 steel were represented by material model 15 (*MAT_JOHNSON_COOK) in LS-DYNA [21]. In this model, the material properties of face sheets can be same as the experiments. Johnson and

Cook [22] express the flow stress as:

$$\sigma_y = f(\bar{\varepsilon}^p)g(\dot{\varepsilon})h(T) = (A + B\bar{\varepsilon}^{p^n})(1 + C \ln \dot{\varepsilon}^*) (1 - T^{*m}) \quad (1)$$

Where: σ_y is equivalent stress; $\bar{\varepsilon}^p$ is effective plastic strain; $\dot{\varepsilon}^* = \dot{\varepsilon}^p / \dot{\varepsilon}_0$ is the homologous; temperature $T^* = (T - T_{room}) / (T_{melt} - T_{room})$; A , B , C , and m are material constants. The expression in the first bracket gives the stress as a function of strain for $\dot{\varepsilon}^* = 1.0$, and $T^* = 0$. The expressions in the second and third brackets represent the effects of strain rate and temperature respectively.

In order to describe ductile fracture, J R Johnson and W H Cook [22] have established a model, which considered the effect of stress triaxiality, temperature and strain rate on failure strain. The Johnson-Cook damage model is a cumulative damage-fracture model considering the loading history, which is presented by the strain to fracture. In other words, Johnson-Cook model assumes that the damage in the material during plastic straining and the material breaks immediately when the damage reaches a critical value, which means that the damage has no contribution on the stress field until the fracture happens. Z T Guo [23] investigated the penetration failure of A3 steel by performing experiments and obtained the failure strain variation tendency with average stress triaxiality.

The nylon core made of PA6 is represented by material model 3 (*MAT_PLASTIC_KINEMATIC) in LS-DYNA, and the ADD_EROSION option is also used to describe the failure of materials (the strain at failure point was set as 0.6 in this article). The Cowper-Symonds model [24] which scales the yield stress by the strain rate dependent factor is as follows:

$$\sigma_Y = \left[1 + \left(\frac{\dot{\varepsilon}}{C} \right)^{\frac{1}{P}} \right] (\sigma_0 + \beta E_P \varepsilon_P^{eff}) \quad (2)$$

Where: σ_0 is the initial stress; $\dot{\varepsilon}$ is the strain rate; C and P are the Cowper-Symonds strain rate parameters; ε_P^{eff} is

the effective plastic strain; E_P is the plastic hardening modulus given by $E_P = E_{tan} E / (E - E_{tan})$. Material types and main mechanical properties of sandwich plates and the two projectiles used in the simulation are listed in Table 4.

5 Simulation results and discussion

5.1 Comparison between experiment and simulation results

In order to verify the numerical method, the same size of sandwich plates and initial velocity of projectiles are selected, and the failure mode of sandwich plates is investigated by penetration tests and numerical method. The penetration test and numerical results of blunt-nosed and hemispherical-nosed projectiles are compared in Figure 9.

As shown in Figure 9, for different projectiles, failure modes of sandwich plates obtained by numerical simulation and penetration tests coincide very well, which verifies the correctness and applicability of the numerical method.

For sandwich plates with various structural forms, penetration tests and numerical simulation are conducted, and experimental and numerical results are compared and shown in Table 5.

As shown in Table 5, the maximum error between numerical and experimental results is 8.63%. In the penetration tests, projectiles cannot guarantee the same absolute vertical penetration of sandwich plates, and a slight angle makes the projectile on the sandwich plate invasion slightly smaller. So simulation results are a little larger than experimental results, and it can be proved that this projectile penetration of steel / nylon sandwich plate simulation is reliable.

Table 4: Input data in the numerical simulation Ref. [23]

Material	Part name	Input data (unit=cm, g, μs, K)						
Die steel	Projectile	*MAT_RIGID						
		RO	E	PR				
		7.8	2.0	0.3				
A3 steel	Face-sheet	*MAT_JOHNSON_COOK						
		RO	E	PR	T _{room}	T _{melt}	A	B
		7.8	2.06	0.29	293	1795	240E-5	230.2E-5
		n	C					
		0.578	0.0652	0.706	2.1E-9	-0.0193	3.811	
PA6	Core	*MAT_PLASTIC_KINEMATIC						
		RO	E	PR	σ _y	E _{tan}	C	P
		1.14	3.3E-2	0.41	60E-5	1.275E-2	1420	0.542

Table 5: Numerical and experimental results of sandwich plates

Serial number	Types of projectiles	Initial velocity of projectiles ($\text{m}\cdot\text{s}^{-1}$)	Penetration depth (mm)		Relative to the experimental error (%)
SP1-2	blunt	252.40	5.65	5.87	3.89
SP1-3	blunt	215.84	3.63	3.86	6.34
SP1-4	hemispherical	250.53	7.01	7.09	1.14
SP1-5	hemispherical	217.39	6.42	6.55	2.02
SP2-1	blunt	247.90	3.97	4.24	6.80
SP2-2	blunt	219.91	2.78	2.87	3.24
SP2-4	hemispherical	242.38	5.39	5.46	1.30
SP2-5	hemispherical	216.11	4.02	4.05	0.75
SP3-1	blunt	256.45	3.36	3.65	8.63
SP3-4	hemispherical	251.47	4.40	4.67	6.14
SP4-1	blunt	244.27	3.10	3.29	6.13

Figure 9: Experimental mode and numerical mode of steel/nylon sandwich plate

5.2 Impact process analysis

Due to the limitation of the experimental conditions, the projectile sometimes fails to go through the sandwich plate. For the projectile with high speed (Impact velocity: $900 \text{ m}\cdot\text{s}^{-1}$), the finite element software LS-DYNA will be used to simulate the penetration process of the steel/nylon sand-

wich plate, and the dynamic deformation and failure modes of sandwich plates are shown in Figure 10.

Figure 10: Deformation of steel-nylon sandwich plates impacted by blunt-nosed projectile

5.3 Ballistic limits of face-sheet thickness

To investigate the effect of face-sheet thickness on the anti-penetration performance of sandwich plates, five different face-sheet thicknesses are selected to conduct the numerical analysis. In the previous section, the thickness of the face-sheet is usually 0.1 mm~2 mm. In this section, the thickness of the face-sheet is 0.5 mm, 0.8 mm, 1.0 mm, 1.5 mm and respectively, and the thickness of the nylon core is 30 mm.

The trajectory limit velocity is also an important parameter for the anti-penetration performance of sandwich plates. For sandwich plates with different thicknesses, R F Recht and T W Ipson [25] proposed the ballistic limit velocity and the relevant parameters, shown in Table 6 and Figure 11.

As shown in Figure 11, the residual velocity of the projectile gradually increases as the initial impact velocity increases, and the trajectory limit velocity of the sandwich plate gradually increases as the thickness of the sandwich plate face-sheet increases. As the initial impact velocity of the projectile increases, the difference between the residual velocities of the projectile gradually decreases.

For the sandwich plates with same core thickness, the weight of sandwich plates will gradually increase as the thickness of the face-sheet increases, and the anti-penetration performance of the sandwich plates will also gradually increase. For sandwich plates with the same core thickness and different face-sheet thickness, corresponding trajectory limit speed curves are shown in Figure 12.

As shown in Figure 12, the trajectory limit velocity of the sandwich plate gradually increases as the face-sheet

Table 6: Ballistic limits and model constants of sandwich plate with various thicknesses of face-sheets

Projectile	Sandwich plates	a	$v_{bl} \text{ (m}\cdot\text{s}^{-1}\text{)}$	p
Blunt	0.5+30+0.5	0.880	563.0	1.681
	0.8+30+0.8	0.871	630.1	1.679
	1.0+30+1.0	0.866	644.1	1.676
	1.5+30+1.5	0.728	680.2	1.934
	2.0+30+2.0	0.707	715.2	1.879
Hemispherical	0.5+30+0.5	0.905	587.8	2.178
	0.8+30+0.8	0.916	605.4	2.156
	1.0+30+1.0	0.927	618.3	2.057
	1.5+30+1.5	0.887	636.4	2.114
	2.0+30+2.0	0.841	649.3	2.111

(a) blunt-nosed projectile **(b)** hemispherical-nosed projectile**Figure 11:** Residual velocity of steel/nylon sandwich plates versus impact velocity for different thicknesses of face-sheets **(a)** blunt-nosed projectile **(b)** hemispherical-nosed projectile**Figure 12:** Weight of steel/nylon sandwich plates versus ballistic limits

Figure 13: Variation of impact energy versus percentage absorbed through sandwich plates

thickness increases, and the face-sheet thickness can increase the overall ballistic limit of the sandwich plate.

5.4 The energy absorption coefficient of different sandwich plates

When the initial impact velocity of the projectile is larger than the trajectory limit speed of the sandwich plate, the projectile will break through the sandwich plate. In this process, the velocity attenuation of the projectile caused by the air friction will be ignored, and the lost energy of the projectile penetrating the sandwich plate can be expressed as follows:

$$E_t = \frac{1}{2} m_p v_i^2 - \frac{1}{2} m_p v_r^2 \quad (3)$$

Where: m_p is the mass of the projectile; v_i is the initial velocity of projectile; v_r is the residual velocity of the projectile; E_t is the loss kinetic energy of the projectile.

Compared with the energy absorption efficiency of other different structures, the percentage of the impact energy absorbed by the sandwich plate can be expressed as follows:

$$\frac{E_t}{E_k} = \frac{\frac{1}{2} m_p v_i^2 - \frac{1}{2} m_p v_r^2}{\frac{1}{2} m_p v_i^2} \quad (4)$$

Where: E_k is the initial kinetic energy of the projectile.

For sandwich plates with different face-sheet thicknesses, the relationship between the percentage of energy absorbed and the initial impact energy of the projectile is shown in Figure 13.

As shown in Figure 13, the energy absorption efficiency of the sandwich plate increases as the face-sheet thickness increases. Take the sandwich plate with face-sheet thick-

ness of 0.5 mm for example. When the initial velocity is $766 \text{ m}\cdot\text{s}^{-1}$, the impact energy is 1994.97 J, and the energy absorbed by the sandwich plate is 1229.52 J. For the sandwich plates with face-sheet thickness of 0.8 mm, 1.0 mm, 1.5 mm and 2.0 mm, the total energy absorption of sandwich plates is 1331.09 J, 1366.66 J, 1454.45 J and respectively. The energy absorption efficiency increases by 8.3%, 11.6%, 18.3% and 26.2%, while the weight of sandwich plates increases by 11.1%, 18.6%, 37.1% and 55.7% respectively. The overall quality of the sandwich plate improves as the face-sheet thickness increases. When the face-sheet is relatively thin, the increasing velocity in the overall energy absorption efficiency gradually raises. When the face-sheet is relative thick, the energy absorption efficiency of the sandwich plate declines as the thickness of the face-sheet increases, and the increasing velocity of the energy absorption is less than that of the weight. For the sandwich plate with the same face-sheet thickness, the energy absorbed increases as the initial velocity of the projectile increases, which is called “energy dissipation rate effect”, but the increasing velocity of the rate gradually decreases.

6 Conclusions

In this paper, the dynamic compression performance of nylon was investigated with Hopkinson Pressure Bar. High velocity impact response and anti-penetration performance of sandwich plates with nylon core and A3 steel were investigated by numerical and experimental methods. The new method developed is the collaboration of the numerical simulation and the experimental method, which greatly

improves the computational accuracy of the numerical simulation, and cut off a lot of time.

The penetration process of projectiles into sandwich plates can be simulated well by LS-DYNA, and numerical results agree well with penetration tests. The failure modes of sandwich plates under blunt-nosed projectiles and hemispherical-nosed projectiles impact are quietly different. The face-sheet thickness can increase the overall ballistic limit of the sandwich plate, and the trajectory limit velocity of the sandwich plate gradually increases as its weight increases. For the sandwich plate with the same face-sheet thickness, the energy absorbed gradually increases as the initial velocity of the projectile increases.

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