

Study on Ballistic Absorbing Energy Character of High Performance Polyethylene Needle Felt

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Abstract. The ballistic performance of polyethylene needle felt is tested and the failure morphology after test is also observed. The results showed that when the non-dimensionally non-stressed fibers in polyethylene needles are subjected to high-speed projectile, secondary movement such as stretching and twisting occurs first. This secondary movement is very full, it is the main way of ballistic absorbing energy of the polyethylene needle felt which can avoid the polyethylene fiber short-term rapid heating-up and destroyed. Analysis results show that under normal temperature and humidity conditions, the V50 of 6-layer forded polyethylene needle felt sample is 250m/s. At (450 ± 50) m/s speed range of the target missile, the mean value of the penetrative specific energy absorption for 3-layer forded polyethylene needle felt anti-1.1g simulated projectiles (tapered column) reaches $24.1\text{J}\cdot\text{m}^2/\text{kg}$.

1. Introduction

Since the 1960s, the war has been constantly around the world, the military equipment industry has been developed rapidly, the development and research of bullet-proof materials have got more and more attention and a series of bullet-proof new materials are developed and applied [1 2]. The software bullet-proof material is highly valued due to its excellent performance such as low quality, high performance and good wearing comfort [3 4].

High-performance polyethylene fibre as a thermoplastic organic fibre has excellent physical properties [5]: low density (only $0.97\text{kg}/\text{m}^3$), linear straight chain molecular structures, orientation degree approximate 100%, high strength (3.0~3.6GPa). But the disadvantage is that the melting point is low. When woven fabric made of high-performance polyethylene fiber is impacted by the high-speed shrapnel, the strain rate of the polymer can reach 10^5s^{-1} or more, at this point the polymer chain is too late to move in a short time. Some secondary sports: vibration, rotation, etc. due to the effect of woven weaving force cannot deform to absorb energy too. So when polyethylene fiber woven fabric bullet proofs bullets, it is extremely easy to friction heat and burn which results in not very satisfactory bullet-proof performance [6].

The state of the fibers in the polyethylene needle felt is completely in a non-dimensionally non-stressed state, which is completely different with the fibers in coven fabric. In this study, the bullet-proof energy absorption performance of needle felt made of high performance polyethylene fiber was investigated.

2. Experimental

The raw materials of the experiment were polyethylene monofilament with diameter of 1.5D and mechanical properties $\geq 30\text{CN} / \text{dtex}$ and length of 100mm. A needle punching process was used to produce a polyethylene needle felt with a thickness of about 2 mm and an area density of (200 ± 15) g. The sample size of ballistic impact test was (400×400) mm. Samples forded of six layers and three



layers of the above size of polyethylene needle felt were used respectively to test the ballistic limit speed V50 and penetration specific energy absorption.

Ballistic experiment was carried out at room temperature and humidity conditions using 1.1g tapered column fragment simulated projectile which were made of 45 steel with hardness of 30HRC. And the size of simulated projectile was shown in figure 1. The trajectory limit speed V50 of test target was measured with reference to the public safety industry standard GA950-2011. A 12.7mm ballistic speed gun was used, the speed forward and behind target of simulated bullet penetration test were measured by the light curtain speed target. The impact incident speed, penetration residual speed and ballistic limit speed V50 of simulated projectile were got by correcting the results of light screen target speed. During the test, the target plate is fixed on the target frame, and the periphery of the target is bound and clamped by the frame. The firing distance used in the experiment (ie, the distance from the launch device port to the fiber target) is 5m, and the shooting direction is vertical to target plate. The shooting test was shown in figure 2 [7]. The Lecia-S6E type Leica microscope and JSM-6000 SEM were used to observe the damage morphology of the polyethylene needle felt after the ballistic experiment.

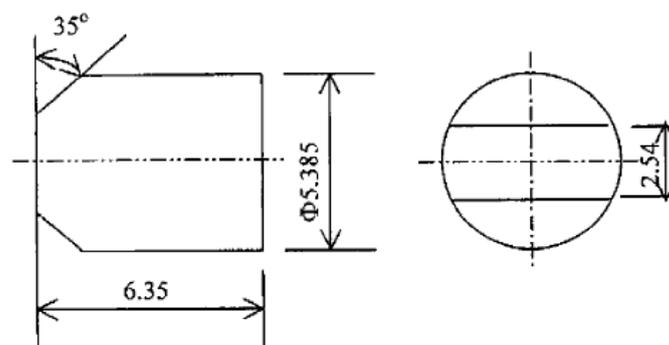


Figure 1. The shape and size of tapered column simulated missile (mm).

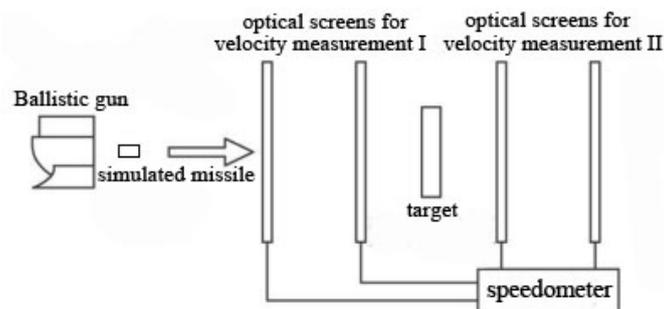


Figure 2. The schematic of shooting experiment.

3. Experimental results and analysis

3.1 Morphological analysis

Figure 3(a) is the original topography of the polyethylene needle felt. It can be seen from the figure that the polyethylene fiber is a non-dimensionally non-stressed state in the needle felt. The movement of fibers in the polyethylene needle felt is different from woven fabric under the impact of high-speed fragment. The stress of the fibers in the polyethylene needle felt is only positive stress which stretches the fiber along impact point, as the show of figure 3(b). The tensile deformation of the fiber in the polyethylene needle felt is more adequacy than woven fabric. As the show of figure 3(c), the fibers in the polyethylene needle felt are stretched by 13mm along the direction of projectile movement at the impact speed of 300m/s. So when the polyethylene needle felt is impacted, the first occurrence of fiber is the tensile deformation of the secondary movement which is the main means of energy absorption.

Followed by the secondary movement of polyethylene fibers there is plenty time for the polymer chains in the fiber to give the reaction to absorb the energy of the fragment.

The figure 3(d) is the SEM microstructure of the polyethylene felt after the impact of the fragment, and the splitting and tensile fracture of fibers did not appear at the impact point. But there is a significant melting and softening phenomenon, the occurrence of high temperature damage is mainly due to the friction between the fibers and the high-speed fragment. When the local temperature exceeds the glass transition temperature of the polyethylene fiber, the mechanical properties of the fibers are rapidly reduction which makes the polyethylene felt loss the protective effect. Therefore, the main failure mode is the softening or melting of the fibers caused by the high temperature when the polyethylene needle felt is impacted by the fragment. Secondly, from the torsion zone in figure 3(d) can be seen that the polyethylene fiber has obvious differences in axial stretching and compression, the anti-shear ability and anti-axial compression capacity is relatively weak.

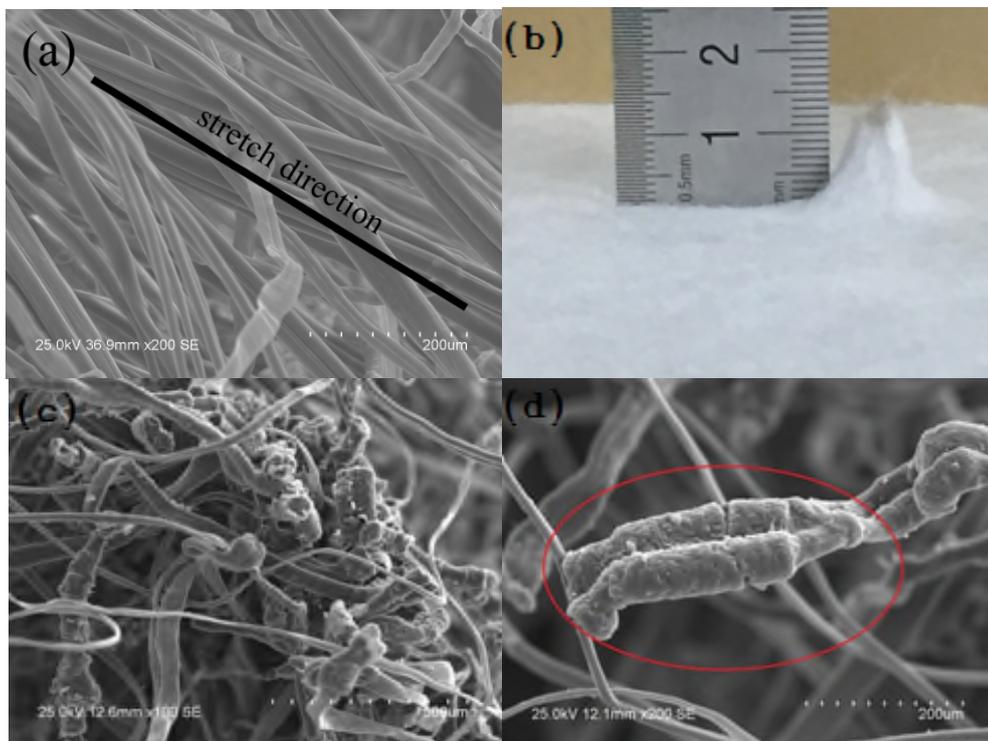


Figure 3. The topography of polyethylene needle felt after ballistic impact.

3.2 Ballistic performance analysis

According to the GA 950-2011 (V50 test method for ballistic materials and products), the V50 test was carried out on 6-layers of the above-mentioned polyethylene needle-felt samples using 1.1g columnar wedge-shaped fragment simulated projectiles and the results show in table 1. The standard deviation is 13.2m/s and the \bar{V} (average velocity of the test points) is 260.5 m/s. According to the conversion formula $V50 = \bar{V}e^{-ax}$ (a is the flying attenuation coefficient of the missile, and x is the flight distance from the measuring point to the target), the V50 of the 6-layer polyethylene needle felt was calculated to be 250 m/s. Table 2 is the V50 values of polyethylene needle felt and other fabric target samples, through the comparison can be found that polyethylene needle felt has good bulletproof energy absorption performance.

Table 1. The V50 test results of polyethylene needle felt.

Numbers	Projectile velocity (m/s)	Test results
1	271.1	unpenetrated
2	429.2	penetration
3	549.2	penetration
4	211.4	unpenetrated
5	295.1	penetration
6	299.9	penetration
7	304.9	penetration
8	252.1	penetration
9	332.1	penetration
10	269.0	penetration
11	239.0	unpenetrated
12	258.8	unpenetrated
13	272.8	penetration

Table 2. The polyethylene needle felt ballistic performance comparison with others [8].

Target sample	Single-layer surface density (g/m ²)	Layer number	Target density (kg/m ²)	V50 (m/s)
CT736 (resin content20%)	510	17	8.71	645
CT709 multi-layer fabrics	220	26	5.24	583
Gold Flex	230	23	5.34	510
polyethylene needle felt	200	6	1.2	250

At (450±50) m/s speed range of the target missile, the perforation specific energy absorption of the three-layer polyethylene needle felt composite samples were tested and the results are shown in table 3. The results show that polyethylene needle felt has a good penetration of energy absorption performance, the mean value of the penetrative specific energy absorption reaches for 3-layer forded polyethylene needle felt anti-1.1g simulated projectiles (tapered column) reaches 24.1J·m²/kg. The main means of energy absorption is the tensile deformation of fiber as show in figure 3.

Table 3. The test results of penetrative specific energy absorption.

Sample number	Shooting number	Impact velocity (m/s)	Residual velocity (m/s)	Perforation specific energy absorption (J·m ² /kg)
1#	1	406.6	371.4	23.9
	2	450.6	424.5	19.9
	3	413.9	376.9	25.5
	4	450.8	419.7	23.6
	5	490.9	468.2	19.0
	6	429.6	390.2	28.2
2#	7	446.5	424.7	16.5
	8	430.1	385.5	31.8
	9	454.5	424.5	23.0
	10	435.1	397.4	27.4
	11	424.7	376.3	33.9
	12	454.2	430.9	18.0
Mean value of perforation specific energy absorption (J·m ² /kg)				24.1

Conclusions

Polyethylene needle felt has a good energy absorption performance. The V50 of the 6-layer polyethylene needle felt is calculated to be 250 m/s. At (450 ± 50) m/s speed range of the target missile, the mean value of the penetrative specific energy absorption for 3-layer forded polyethylene needle felt anti-1.1g simulated projectiles (tapered column) reaches $24.1\text{J}\cdot\text{m}^2/\text{kg}$. The main way of ballistic absorbing energy is the secondary movement. When the non-dimensionally non-stressed fibers in polyethylene needles are subjected to high-speed projectile, secondary movement such as stretching and twisting occurs first and this secondary movement is very full, so it is the main way of ballistic absorbing energy. High temperature melting is the main way for the fragments to break the polyethylene needle felt.

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