〔보 문〕

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An Evaluation of the Protection Efficiency of Ballistic Material
방탄소재 구성에 따른 방호성능 평가에 관한 연구

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Abstract

본고는 지뢰 방호복을 개발, 국산화하기 위해 먼저 방탄소재 구성방법에 관하여 실험한 결과이다. 기존의 여러 겹의 파라-아라미드(Para-aramid)나 단순히 파라-아라미드와 폴리 에틸렌 필름(Polyethylene film)을 조합한 소재구성과는 달리 케블라 파이버(Kevlar fiber)로 만들어진 펠트(felt)를 첨가하여 방탄원리 및 특성을 고려한 구성으로 방호복의 중량을 줄이면서 착용자로 하여금 유연성과 동작성을 향상시켜 임무수행과 안전성을 높일 수 있는 방호복을 개발하고자 하였다.

1) Para-aramid(내 충격열) + Flex-felt(충격 에너지 흡수) + Para-aramid(backface) + Polyethylene film(에너지 분산 극대) + Para-aramid(내 마찰열, backface) 순으로 소재를 배열함으로써 기존의 Para-aramid 36겹에 대하여 Para-aramid 13겹, Polyethylene film 13겹, 그리고 펠트 1겹으로 동일한 방호성능을 얻었다.

2) 새로운 소재 구성 방법에 의한 방탄소재는 동일한 방호성능을 갖는 기존의 소재 구성방법에 따른 방탄소재보다 중량에서 34-19% 더 가벼운 것으로 나타나 방호복 구성 시 유연성이나 동작성에 유리할 것으로 사료된다.

3) NIJ-STD-0101.03에서의 Armor type II에 해당하는 시편 I의 방호한계속도로 구한 운동 에너지량은 154.4J, Armor type III-A에 해당하는 시편 II의 방호한계속도로 구한 운동 에너지량은 183.0J로 나타나 두 시편 모두 5m의 거리에서 M16A1 지뢰의 0.032~0.044g 사이의 파편에 대해서 50%의 관통확률을 갖는 것으로 나타났다.

Key words: de-minning suit, protection efficiency, ballistic material composition, Kevlar needle-felts, Polyethylene film;
지뢰 제거복, 방호성능, 방탄소재 구성, 케블라 니들펠트, 폴리에틸렌 필름

I. Introduction

Ever since the summit conference with North Korea, the necessity for the detecting and de-minning operations has become an increasing priority, as has the importance of investigating the effectiveness and durability of the protection gear worn by participating military personnel. In order to ensure activity, flexibility and lightness, the clothes should have minimal bulk.

Burnett(CLOTHING, Susan M. Watkins, p.115, 1995) notes that needle-felts are generally not used alone, but rather in conjunction with other woven or knitted fabrics . He goes on to state that a synergistic effect often exists when Kevlar needle-felts and woven fabrics are used in combination. A woven and a needle-felt fabric can give better performance than two woven fabrics.

Protection gear is developed to diminish the risk of death or severe injury from land mines and explosions. Advanced countries have inserted a steel plate, hybrid with Kevlar laminate and Spectra shield and panel of thermal molding, for greater protection from fragments.

Allied Fibers, of the U.S.A. has recently introduced the Spectra shield as an innovative system for ballistic protection. This system utilizes high-performance Spectra fibres(unidirectional) and a resin matrix. This creates layers of film, which can be stacked to from a pliable material for soft body armour.

Most traditional ballistic armour used for bullet-resistant vests relies on multiple layers of woven fabric. The number of layers dictates the degree of protection. Since new bullets can easily penetrate traditional Kevlar vests, 30 layers of neoprene coating are required for improving the performance of bulletproof vests. However, the Spectra shield is able to achieve the same level of protection with 33% less weight.

Kunzendor(Protection Clothing, Textile Institute, pp.66-68, 1992) has reported on the constructional parameters for bulletproof vests. One form of non-woven fabric, needle-felt has been found useful in marking ballistic-protective textiles. Felts with a very low mass per unit area are therefore probably the most effective materials for ballistic protection, but, as the mass increases, woven textile are superior to felt in performance.

Accordingly, this is a study on new ballistic material composition with Kevlar needle-felts added in to obtain better protection efficiency with less weight. The ballistic protection efficiency and weight of test sample II made of the new ballistic material composition compares with existing material composition in accordance with NIJ-STD-0101.03.

A measure of the efficiency of test sample I and II in this study was considered on the basis of a certain projectile speed, approximately V50, at which speed the projectile would retain the fragments of a simulating projectile(FSP).

II. Experiment

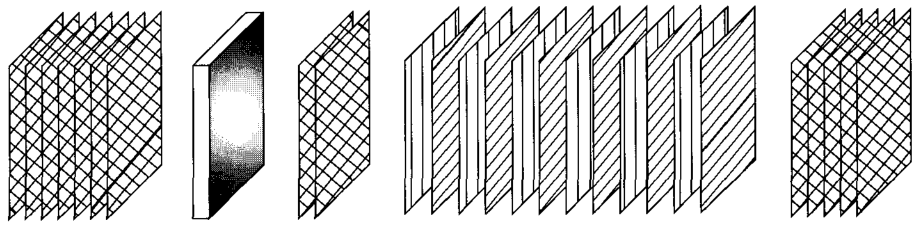
1. The Physical Properties of material

The physical Properties(weight, fabric count, density, tensile strength, tenacity, modulus, elongation at break, and decomposition) of Para-aramid, Polyethylene film, and Flex-felt are measured.

2. Test sample plate

The Protection efficiency of new ballistic material composition is Armor type II and III-A of NIJ-STD-0101.03. It is material with an added layer of Flex-felt, such as Para-aramid+Flex-felt+Para-aramid+Polyethylene film+Para-aramid in sequence.

Figure 1 shows two test sample plates which are sample I(Para-aramid(six layers)+Flex-felt(one layer)+Para-aramid(one layer)+Polyethylene film(eleven layers)+Para-aramid(three layers)) which is Armor type II and sample II(Para-aramid(seven layers)+Flex-felt(one layer)+Para-aramid(two layers)+Polyethylene film(twelve layers)+Para-aramid(five layers)) which is Amor

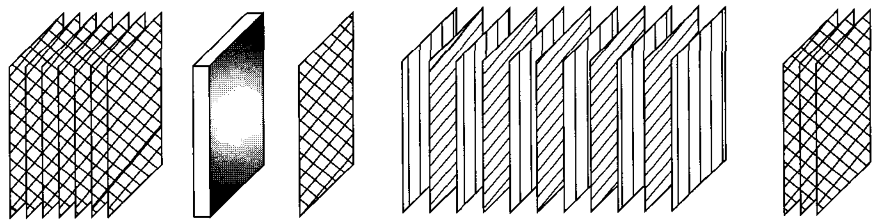


① Para-aramid(6 layers)

+ ② Flex-felt(1 layer)

+ ③ Para-aramid(1 layer) + ④ Polyethylene film(11 layers) + ⑤ Para-aramid(3 layers)

[Sample I]



① Para-aramid(7 layers)

+ ② Flex-felt(1 layer)

+ ③ Para-aramid(2 layers) + ④ Polyethylene film(12 layers) + ⑤ Para-aramid(5 layers)

[Sample II]

Fig. 1. Layering Ballistic Material

type III-A of NIJ-STD-0101.03.

Para-aramid of ① and ③ are diamond style quilted. Para-aramid of ⑤ is box style quilted. Polyethylene film of ④ is unidirectional fibers shield. Para-aramid at the front resists high-energy impact heat. It is high heat-resistant, has low heat-expansion, and low heat-conduction.

Flex-felt of ② absorbs impact to the utmost and is flexible and light. The back is layered with Para-aramid, which provides high-energy impact protection : tensile strength, modulus, and breaking elongation.

Polyethylene film disperse high-energy impact. The back of para-aramid resists friction heat and reduces deformation to the minimum.

3. Comparison of protection efficiency and weight

The ballistic protection efficiency and weight of test sample II made of the new ballistic material composition compares with existing material composition in accordance with NIJ-STD-0101.03. Table 1 shows required protection performance by armor type in accordance with NIJ-STD-0101.03.

4. V_{50}(ballistic limited velocity)

V_{50} ballistics limit is commonly used to report ballistics test results. It is the internationally recognised standard for assessing the fragmentation resistance of personal armor. A standard projectile(Caliber 22 FSP) is fired at the

Table 1. The required protection performance by armor type in accordance with NIJ-SZTD-0101.03

Armor Type	Test Ammunition	Nominal Bullet Mass (g)	Required Bullet Velocity (m/s)	Maximum Trauma (nm)
I	22 KRHV Lead	2.6	320	44
	33 Special RN Lead	10.2	259	44
Ⅱ-A	357 Magnum JSP	10.2	381	44
	9mm FMJ	8.0	332	44
Ⅱ	357 Magnum JSP	10.2	425	44
	9mm FMJ	8.0	358	44
Ⅲ-A	44 Magnum Lead SWC	15.55	426	44
	9mm FMJ	8.0	426	44
Ⅲ	7.62mm Win FMJ	9.7	838	44
Ⅳ	30-60 AP	10.8	868	44

NOTE: RN; Round Nose, AP; Armor Piercing, FMJ; Full Metal Jacketed, JSP; Jacketed Soft Point, LRHV; Long Rifle High Velocity

test material at increasing velocities until 50% of the shots penetrate.

The protection efficiency of sample I and II is measured to ballistic limited velocity. The test equipment is 5.56mm test barrel, Model 292 barrel rest, and firing system made in Austria, and Model 4010P velocity measurement and test sample plate made in America. Figure 2 shows the arrangement of the test equipment.

The ballistic limited velocity is measured by an Up-&-Down method using three shots of complete penetration and three shots of partial penetration. When the spread velocity is measured less than 38.1m/s or 45.7m/s, the ballistic limited velocity is calculated to the arithmetic mean. Complete penetration is decided to Protection Ballistic Limit.

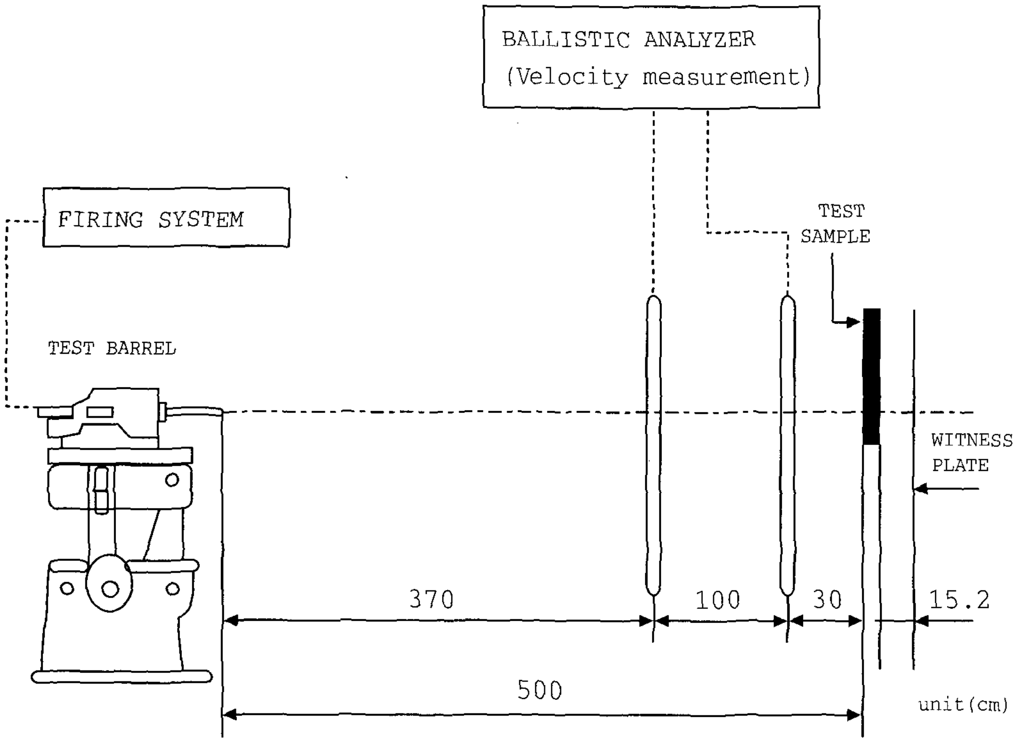


Fig. 2. Arrangement of Test Equipment

5. The penetration rate of test samples to land mine M16A1

The penetration rate of test samples to land mine M16A1 is estimated with kinetic energy.

Kinetic energy(E)=$1/2mv^2$, m=fragment weight, v=fragment velocity

Ⅲ. Results

1. The physical properties of material

Table 2 shows the physical properties of ballistic material in use in this study.

Table 2. The physical properties of material

Item \ Subject		Para -aramid	Polyethylene film	Flex -felt
Weight(g/m^2)		205.00	160.00	613.00
Fabric count (picks/inch)		30×30	N/A	N/A
Density(g/cm^3)		1.44	0.97	1.44
Tensile strength(GPa)		2.70	2.70	-
Tenacity	N/tex	1.90	2.65	-
	g/den	22.00	30.00	-
Modulus(GPa)		58.00	87.00	-
Specific modulus	N/tex	40.00	90.00	-
	g/den	450.00	1000.00	-
Elongation at break(%)		3.70	3.50	-
Decomposition point(℃)		432~583	140~150	-

2. Comparison to protection efficiency and weight

Table 3 is the protection efficiency test result of sample II. Sample II made of the new ballistic material composition obtained level of III-A protection efficiency with fewer layers than the existing ones. Accordingly, Sample II made of polyethylene film 13 layers+para-aramid 13 layers+flex- felt 1 layer is same as the existing material composition, 36 layers of para-aramid or hybrid of para-aramid and polyethylene films.

Table 4 shows that the weight of new material composition is lighter by about 34-19% than one of existing material composition. This result is consistent with the conclusions of Kunzendor

Table 3. Test result of sample II in accordance with NIJ-STD-0101.03

Test Sample				Ballistic Threat			Results			
No.	Tested	Weight (lbs)	Plies	Obliquity (degrees)	Caliber	Shots	Velocity(m/s) Max.	Velocity(m/s) Min.	Penetration	Trauma (mm)
1	front-wet	6.16	26	0	.44 Mag.	4	446.8	435.8	0	44
				30	.44 Mag.	2	440.0	427.0	0	na
	back-wet	4.55	26	0	.44 Mag.	4	448.9	435.5	0	37
				30	.44 Mag.	2	443.2	441.6	0	na
2	front-dry	6.16	26	0	.44 Mag.	4	444.4	428.5	0	43
				30	.44 Mag.	2	433.4	428.5	0	na
	back-dry	4.55	26	0	.44 Mag.	4	434.3	431.6	0	36
				30	.44 Mag.	2	437.9	430.4	0	na
3	front-wet	6.16	26	0	9mm	4	437.9	436.1	0	27
				30	9mm	2	435.8	434.9	0	na
	back-wet	4.55	26	0	9mm	4	437.4	434.0	0	28
				30	9mm	2	435.5	434.3	0	na
4	front-dry	6.16	26	0	9mm	4	437.7	434.6	0	27
				30	9mm	2	436.8	436.5	0	na
	back-dry	4.55	26	0	9mm	4	437.4	436.1	0	30
				30	9mm	2	437.9	435.8	0	na

Table 4. Comparison of sample II made of new material composition in new ballistic material composition with existing material composition.

Item	Existing material composition		New material composition
	one material	two material hybrids	three material Hybrids
Composition method	Para-aramid 36 layers	Para-aramid 18 layers Polyethylene film 18 layers	Polyethylene film 13 layers Para-aramid 13 layers Para-aramid felt 13 layers
Weight	36 layers × 208g/m^2 =7488 total weight=7488g/m^2	18 layers × 208g/m^2=3744 18 layers × 160g/m^2=2880 total weight=6624g/m^2	13 layers × 220g/m^2=2860 13 layers × 160g/m^2=2080 1 layers × 613g/m^2=613 total weight=5553g/m^2

(Protection Clothing, Textile Institute, pp.66-68, 1992); the needle-felt has been found useful in marking ballistic-protective textiles.

3. Ballistic limited velocity

1) Ballistic limited velocity of test sample I to fragment simulating projectile

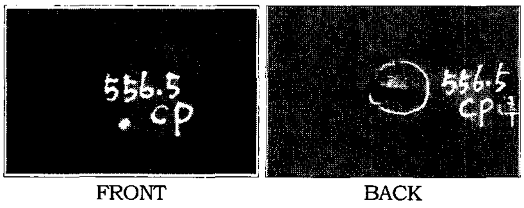
Effective complete penetration mark is demonstrated as ▲, and partial penetration is ▼. Table 5 shows ballistic limited velocity of test sample I to fragment simulating projectile.

Because the spread velocity is measured at 42.4m/s, ballistic limited velocity is calculated to the arithmetic mean using three shots complete penetration and three shots partial penetration. Ballistic limited velocity of test sample I is measured as 528.33m/s.

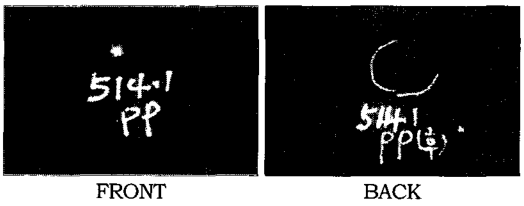
Table 5. Test result of sample I

Round No.	Charge (g)	Striking Velocity(m/s)	Result (CP/PP)	Effective Choice
1	1.000	635.3	CP	
2	0.900	558.3	CP	
3	0.800	489.9	PP	
4	0.800	504.8	PP	
5	0.800	506.1	PP	
6	0.870	537.6	CP	▲
7	0.830	500.8	PP	
8	0.830	520.6	PP	▼
9	0.850	556.5	CP	▲
10	0.840	514.9	PP	▼
11	0.845	514.1	PP	▼
12	0.850	526.3	CP	▲

Figure 3 shows an example of the shapes of sample I after ballistics test. The back of sample I in (a) shows complete penetration, while sample I in (b) shows partial penetration.



(a) Maximum velocity in effective complete penetration(556.5m/s)



(b) Minimum velocity in effective partial penetration(514.1m/s)

Fig. 3. The effects of Caliber 22 FSP on sample I after ballistics test

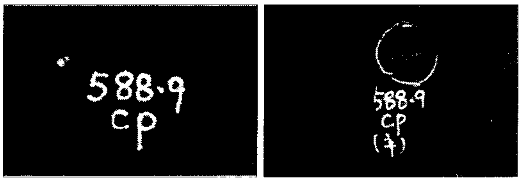
2) Ballistic limited velocity of test sample II to fragment simulating projectile

Table 6 shows ballistic limited velocity of test sample II to fragment simulating projectile. As spread velocity is measured at 20.8m/s, ballistic limited velocity is calculated as 575.26m/s.

Figure 4 shows an example of the shapes of sample II after ballistics test.

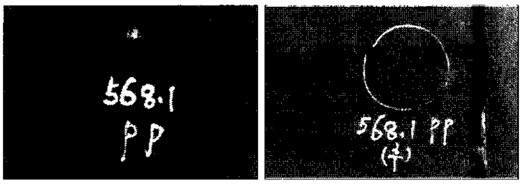
Table 6. Test result of sample II

Round No.	Charge (g)	Striking Velocity(m/s)	Result (CP/PP)	Effective Choice
1	0.900	521.1	PP	
2	0.980	612.7	CP	
3	0.930	588.9	CP	▲
4	0.911	571.1	PP	▼
5	0.912	575.0	CP	▲
6	0.912	537.6	CP	▲
7	0.912	573.1	PP	▼
8	0.912	568.1	PP	▼



FRONT BACK

(a) Maximum velocity in effective complete penetration(588.9m/s)



FRONT BACK

(b) Minimum velocity in effective partial penetration(568.1m/s)

Fig. 4. The effects of Caliber 22 FSP on sample II after ballistics test

Table 7. The number of fragments and the value of kinetic energy of M16A1

Fragments(g)	First time		Second time		Kinetic energy(J)
	fragments account	weight(g)	fragments account	weight(g)	
0.000-0.031	majority	175.350	majority	182.520	0.0- 139.5
0.032-0.044	503	18.678	494	18.354	144.0- 198.0
0.045-0.063	300	15.801	441	23.736	202.5- 283.5
0.064-0.082	167	11.937	279	19.926	288.0- 369.0
0.083-0.101	104	9.594	125	11.244	373.5- 454.5
0.102-0.127	98	11.546	216	25.455	459.0- 571.5
0.128-0.159	327	48.544	604	87.304	576.0- 715.5
0.160-0.191	447	78.332	487	85.873	720.0- 859.5
0.192-0.223	281	58.548	187	38.757	864.0-1003.5
0.224-0.255	307	74.476	201	48.673	1008.0-1147.5
0.256-0.319	364	103.272	160	46.179	1152.0-1435.5
0.320-0.383	30	10.395	345	11.322	1440.0-1723.5
0.384-0.447	27	11.466	75	3.208	1728.0-2011.5
0.448-0.511	24	11.804	10	5.173	2016.0-2299.5
0.512-0.575	9	4.945	9	4.998	2304.0-2587.5
0.576-0.639	6	3.561	10	6.388	2592.0-2875.5
0.640-0.767	12	8.160	13	9.537	2880.0-3451.5
0.768-0.959	12	10.461	12	10.746	3456.0-4315.5
0.960-1.279	12	12.825	12	13.111	4320.0-5755.5
1.280-	21	43.836	22	53.575	5760.0-

4. The penetration rate of test samples by land mine M16A1

Using the weight of fragment simulating projectile, caliber 22 and ballistic limited velocity in this test, the kinetic energy of test samples is measured. Sample I shows 154.4J and sample II shows 183.0J.

Table 7 shows the number of fragments and the value of kinetic energy of M16A1.

The two test samples in this test have a penetration rate of 50% to 0.032-0.044g of M16A1 within 5m.

IV. Conclusions

1) The new ballistic material composition obtained the level of III-A protection efficiency with fewer layers than the existing ones, that is, polyethylene film 13 layers+para-aramid 13 layers+para-aramid felt 1 layer, are the same as the existing material composition, 36 layers of para-aramid or hybrid of para-aramid and polyethylene films.

2) The weight of the new material composition is lighter by about 34-19% than the existing material composition.

3) When the measurement of the ballistic velocity was analogized, using the simulating projected Caliber 22, sample I showed 154.4J, sample II, 183.0J, and also showed that both of them have a penetration rate of 50%, with 0.032-0.044g for M16A1 within 5m.

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