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An evaluation of the suitability of fluorescent fabrics and retroreflective materials for road traffic warning clothing in compliance with international standards

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Abstract

The purpose of this study is to compare and analyze physical properties of different fluorescent fabrics and retroreflective materials to determine their compliance to international standard for high-visibility warning clothing. Four fluorescent fabrics were selected for the study: a PET 71%/Cotton 23%/PU 6% fabric used in public road cleaner uniforms in Korea (S1), an ISO-compliant Japan-made PET 65%/Cotton 35% + conductive fabric (S2), and a randomly selected Korean-made PET 100% fabric for adults (S3) and children (S4). Selected samples were evaluated on their seven criteria in ISO 20471. Subsequently, luminance and retroreflective properties of four retroreflective materials were compared: a 3M (USA) plain sample (R1), a rectangular-patterned sample made by 'R' company (Korea) (R2), a plain sample also by 'R' (R3), and a random plain sample from a marketplace in Korea (R4). As a result, S1 was the most similar to ISO-compliant S2 and moisture regain could be improved by adjusting the cotton ratio or surface finishing. However, S3 and S4 seemed less suitable. Second, two bead type (R1, R4) and two prism type (R2, R3) retroreflective materials showed luminance in the order of R4 > R2 ≥ R1 > R3. General retroreflective properties and post-5-condition retroreflective properties of all four samples were ISO-compliant, and the retroreflective property at observation angle of 12′ and incidence angle of 5° of R2, R3, and R4 against R1 ranged between 81.4% and 158.4%. Despite the variance, all four samples were ISO-compliant and suggest that R2, R3, and R4 are possible materials for export.

Keywords: Warning clothing, Road traffic, Visibility, Fluorescent fabric, Retroreflective material, Comfort sensation, International standards

Introduction

For the prevention and management of road traffic hazards, developed countries have enacted regulations on wearing high visibility warning clothing (ANSI/ISEA 2015; International Organization for Standardization [ISO 20471] 2013; Japan Safety Appliances Association [JSAA] 2017; Japan Traffic Safety Education Association [JATRAS] 2016; JIS T 8127 2015; ORAFOL 1999). Korea is also striving towards global standards by improving traffic safety that regulate the wearing of high visibility warning clothing in compliance with international standards.

Many countries are also following the trends of developed countries to enforce regulations on warning clothing for the public and vulnerable passengers. However, in Korea, there are a lack of academic studies and insufficient R&D. Recent research studies have been completed by the Korea Transportation Safety Authority (KOTSA) (2017), Korea Expressway Corporation (2017), and Korea Road Traffic Authority (2016); however, these studies have focused on safety vests, which are considered substandard and insufficient by ISO standards. This prior research also assumed a traffic study point-of-view rather than a clothing study point-of-view. Therefore, it is necessary to bring about research and development of high-quality warning clothing that is more refined toward the criteria and levels found in international standards.

Current warning clothing needs to be improved in terms of visibility and wear comfort; in addition, it is necessary to consider enforcing the appropriate wearing conditions for warning clothing. Research on warning clothing usage in various fields such as traffic maintenance, road sanitation, and traffic police is ongoing (Han et al. 2013; Huh 2006; KOTSA 2017; Jung and Cho 2006); however, these studies are in their early stages with little incentive to comply with international standards. In the meantime, trial clothing that applies retroreflective material and LED devices has been developed to enhance safety in various environments such as marine, traffic, night time work, leisure/sports, and outdoor children's activities (Han et al. 2013; Kim 2010; Lee 2010; Shin and Lee 2013). In addition, warning clothing requires improved visibility as well as better quality to satisfy the comfort sensation of the wearer, especially for uniforms worn for an extended period of time by workers (Lee 2016; Park 2018).

Fluorescent dyes used to produce warning clothing are water-insoluble and follow the dyeing mechanism of conventional disperse dyes (Lucjan et al. 2004). Fluorescent dyes have super-hydrophobicity and have high affinity toward hydrophobic fabrics. Fluorescent dyes show a behavior in which a molecule transitions to an excited state by the light energy of the absorbed wavelength, and then the absorbed light energy is again emitted as a longer wavelength that returns the molecule to a stable bottom state. Several reports have evaluated the fluorescence intensity of florescent dyes based on dye fastness (Kim et al. 2017). The purpose of using fluorescent dyes is high visibility due to the emission of light; however, a strongly dyed result is not necessarily advantageous because it lowers the reflectance of the dye and produces a darker color. This self-extinguishing phenomenon occurs when the dye concentration is increased excessively and the emitted light is reabsorbed by adjacent dye molecules (Kim et al. 2017). Last, the regulation for evaluating visibility is KS V ISO 15027-1 (Korea Agency for Technology and Standards (KATS 2005).

Retroreflective material used in warning clothing comes various forms such as synthetic resin plates, fabrics, and sheets. Products are often equipped with retroreflective sheets (bead type and micro prism type) that are either patterned or plain. According to KS A 3513 (KATS 2005), retroreflection occurs when incident light is returned to its source while an even distribution is maintained across various incidence and observation angles (Kang and Lee 2017). This study compares and analyzes the properties of fluorescent fabrics and retroreflective materials in order to develop improved warning clothing for road maintenance workers, traffic police, and vulnerable passengers that is highly visible, comfortable and helps prevent traffic accidents.

It also promotes international level warning clothing that meets ISO material and design standards.

Methods

Four fluorescent fabric samples were tested on seven items (air permeability, moisture regain, water vapor permeability, tensile strength and elongation, abrasion strength, rate of size change after washing, and colorfastness) specified by ISO 20471. The samples consisted of a light green color PET (polyester) 71%/C (Cotton) 23%/PU (polyurethane) 6% fabric which is currently used in public worker uniforms in Korea (S1), an ISO-compliant yellow PET 65%/C 35% + conductive fabric 'Brianstar' (2013) manufactured by a Japanese company (S2), a light green PET 100% fabric for adult clothing randomly selected and procured from a Korean special fabric marketplace (S3), and a randomly selected yellow PET 100% Korean fabric for children's clothing (S4).

Four different retroreflective material samples were then selected and tested to determine their level of compliance to international standards: a 3M material (made in USA) (R1), and a rectangular patterned sample manufactured by the Korean 'R' company (R2) (Reflomax 2018), a plain (no pattern) sample also from 'R' company (R3), and a randomly selected plain trial sample sold in the market (R4) that was also made in Korea.

The testing methods according to each evaluation criterion and international standards are described below.

Fluorescent fabrics

Appearance

The surface of four fluorescent fabric samples were photographed at 200× magnification via scanning electron microscope (SEM) (Phenom®, Netherlands). The fabric count was measured by warp and weft/5 cm in accordance with KS K 0511 (2009).

Air permeability

Air permeability was measured using an air permeability tester (Textest®, Switzerland) on a 20 cm × 20 cm surface at constant pressure of 100 pa in accordance with ISO 9237. The measurement was repeated at least 5 times and the average value was used for comparison. The initial measurement unit was mm/s and multiplied by 6 to convert the value into $\mathrm{cm^3/min/cm^2}$ format; $(\mathrm{mm/s}) \times 6 = (\mathrm{cm^3/min/cm^2})$.

Moisture regain

Using the oven method (in accordance with KS K 0220) at 20 °C/65% RH standard state, moisture regain (A) was measured on two sheets per sample, and the average value was used for comparison.

$$A = \left\{(W - W_0)\big/ W_0\right\} \times 100(\%)$$

W_0: absolute dry weight of the fabric, after leaving in a dryer at 100 ± 2 °C for 3 h until the weight difference was within 1%. W: fabric weight after moisture absorption and equilibrated by being left in the atmosphere for 8–24 h.

Water vapor permeability

Using the calcium chloride ($CaCl_2$) method, water vapor permeability was measured for an hour in accordance with KS K 0594 and converted to 24-h.

Tensile strength and elongation

Using the Grab test method (CRE Type) of KS K ISO 0520, tensile strength and elongation were measured in both warp and weft directions, while the gauge length was set at 100 mm.

Abrasion

The breaking point of the test piece was measured using the Martindale method of KS K ISO 1294-2. The final point was set at the threshold of thread breakage and the load was set at 595 ± 7 g.

Rate of size change after washing

A washing method in accordance with KS K ISO 6330 was performed using a Kenmore washing machine, under normal cycle, (30 ± 3) °C, and WOB net drying conditions. The washing load was set at 2.0 kg, and I-type patchwork was used for the test.

Colorfastness

Six essential colorfastness tests (wash, dry-cleaning, sunlight, friction, compound and hot-pressing tests) were performed for the study.

1. Wash

   In accordance with article A2S of KS K ISO 105-C06: 2014, the four samples were washed with ECE standard detergent (containing phosphate) at (40 ± 2) °C for 30 min using Launder O Meter (Asiatest®, Korea). The levels of dye transferring and color change were measured in grades and then compared.
2. Dry-cleaning
   In accordance with KS K ISO 105-D01: 2010, the samples were submerged in perchloroethylene solvent and the ensuing level of color change was examined.
3. Friction
   In accordance with KS K ISO 0605-1: 2017, a Crockmeter method was used to examine the level of color change in dry and wet conditions. Wet white 100% cotton cloth was rubbed against frictional cloth and the level of dye transferring was then compared among three samples.
4. Sunlight
   In accordance with KS K ISO 105-B02: 2014, sunlight colorfastness was tested after the Xenon Arc method 3 with a 100% wool standard blue cloth using Atlas® (USA) testing equipment.
5. Compound

Compound colorfastness due to the combined effect of sweating and sunlight was examined in accordance to KS K 0701: 2014 B (Xenon method) using Atlas® (USA) testing equipment.

6. Hot-pressing
   In accordance with KS K ISO 105 XII, levels of color fading and staining immediately after drying and damping tests at a hot plate temperature of (150 ± 2) °C were measured.

Retroreflective materials

Four retroreflective materials were selected for comparative analysis: a 3M (USA) plain-type sample (R1), a rectangular-pattern-type sample made by Korean company (Reflomax 2018), R2, a plain-type sample also made by 'R' company (R3), and a randomly selected plain sample obtained from a special fabric marketplace in Korea (R4).

Appearance

In order to observe the shape of the surfaces of retroreflective material samples, SEM photographs of the external surface were taken at 100× magnification and the cross-section at 300× magnification.

Chromaticity/luminance

In accordance with ISO 150-J01, chromaticity/luminance of samples were measured with a CIE-D65, 2°, 45/0 method and with Black Underlay using Spectrophotometer CM-2500c (Konica Minolta).

General retroreflective property

The reflective property of each sample was measured in accordance to ISO 20471 (2013) at $\varepsilon = 0°$ and 90°, for observation angles of 12′, 20′, 1°, and 1°30′ and incidence angles of 5°, 20°, 30°, and 40°.

Retroreflective property after 5 conditions

The samples were tested for their retroreflective property after exposure to 5 different conditions described under the following conditions at an observation angle of 12′ (0.2°) and incidence angle of 5°.

Condition 1: Abrasion (BS EN 530: 2010 (method 2), Martindale method. Applied weight 9 kPa, 5000 cycles).
Condition 2: Bending (ISO 7854 Method A (DeMattia Method), 7500 cycles).
Condition 3: Bending at low temperature (ISO 4675, temperature − 20 °C).
Condition 4: Temperature change (heat up to 50 °C for 12 h, then immediately cool to − 30 °C for 20 h).
Condition 5: Washing 5 times (ISO 6330: 2000/Amd. 1: 2008(E) Test Program 2A, (60 ± 3) °C, tumble dry low).

Table 1 Characteristics of 4 fluorescent fabric samples

Sample no.	Materials	Weave construction	Thickness (mm)	Fabric count (warp x weft)/5 cm
S1	PET 71%/Cotton 23%/PU 6%	Fancy plain weave	0.27	313.0 × 210.6
S2	PET 65%/Cotton 35%	Twill weave (Gabardine)	0.38	273.6 × 124.0
S3	PET 100%	Fancy plain weave	0.34	291.2 × 200.8
S4	PET 100%	Plain weave	0.17	259.8 × 196.8

Results and discussion

According to Park (2018), a Korean survey of road cleaners and police officers revealed that their main dissatisfaction with warning clothing is 'humidity and hotness due to poor sweat absorption'. Thus, the study focused on improving such areas of dissatisfaction in order to produce practical results. The results are as follows.

Fluorescent fabrics

Table 1 shows the characteristics of four fluorescent fabrics used in this study. The composition of the fibers largely consisted of PET and the order of their thickness was S2 > S3 > S1 > S4. S4 was only about half of S2 and S3. Fabric count was in the order of S1 > S3 > S2 > S4 in the warp direction and S1 ≥ S3 ≥ S4 > S2 in the weft direction. S1 had the highest warp and weft density.

The structure of the fabric (thickness and porosity) is a factor that determines air permeability and water vapor resistance (Yoon and Buckley 1984). In Table 1 and Fig. 1, it can be deduced from S2 (low density) and S4 (low density and low thickness) that greater porosity and thinner thickness increases water vapor permeability. Behmann (1960, as cited in Nam 2007) reported that moisture evaporation was affected by surface characteristics (Fig. 1), and Mecheels and Umbach (1976, as cited in Tamura 1988) reported that moisture absorption effected comfort. Therefore, related discussions about the results of each experiment are provided.

Appearance

Figure 1 shows scanning electron microscope (SEM) photographs taken at 200× magnification of the four kinds of fluorescent fabrics. The weave construction of S1, S2, S3, and S4 were found to be fancy plain weave, twill weave (gabardine), fancy plain weave, and plain weave, respectively.

Air permeability

Air permeability in comparison to ISO-compliant S2 as the basis (100%) was similar at 101.7% for S1 and 72.4% for S4, but very low for S3 at 20.8% (Table 2). Air permeability is associated with heat transfer and is known to have a great influence on comfort (Mecheels and Umbach 1976; Tamura 1988; The Japan Society of Home Economics 1989). Therefore, S1 and S2, which showed high air permeability, would be more advantageous for comfort in hot weather conditions than the other samples.

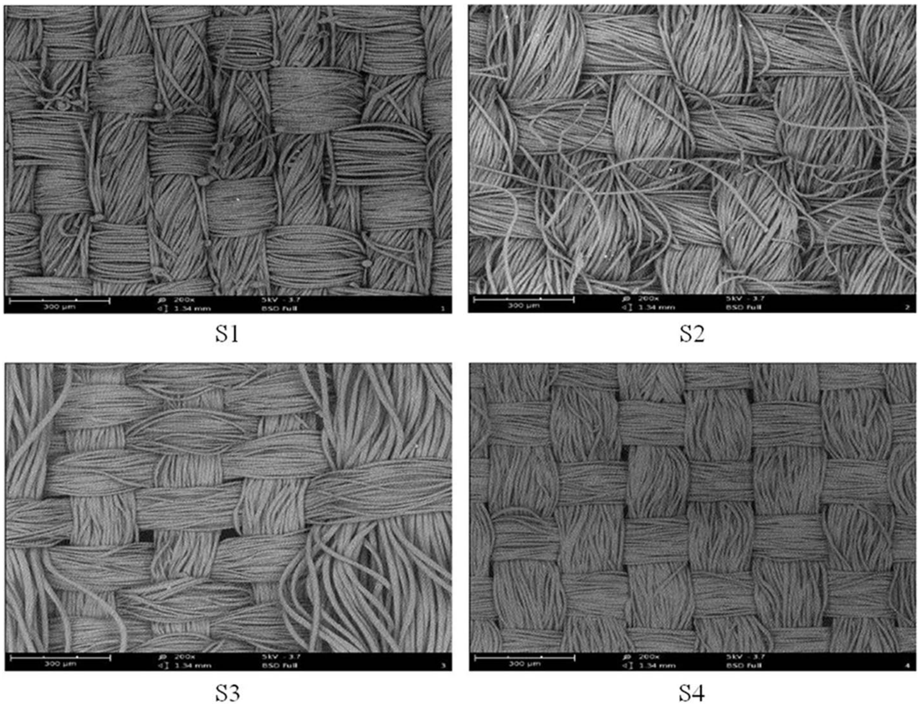

Fig. 1 Morphologies of SEM photos of 4 fluorescent fabric samples

Moisture regain

Increases in skin surface humidity cause unpleasantness and stickiness; therefore, it is desirable that material contacting with the skin has excellent moisture absorption and water vapor permeability qualities (Tamura 1988; Park 1992). In the study, moisture regain was the highest in S2 (1.11%), followed by S1 (0.53%) > S3 (0.10%) ≥ S4 (0.06%) (Table 2). The Korean samples S1, S3 and S4 fell short of ISO standards and PET 100% fabrics were low in moisture regain and expected to be the most uncomfortable during wear.

Water vapor permeability

Fabric water vapor permeability is important for water vapor transportation which influences comfort (Tamura 1988). Water vapor permeability ranked in the order of S2 (10,885) ≥ S4 (10,705) > S3 (9634) > S1 (8998 g/m^2 24 h). Considering S2 as 100%, S4 was 98.3%, S3 was 88.5%, and S1 was 82.7%, but all of them were more than 80% with no major differences (Table 2).

Clothing material air permeability, moisture regain, and water vapor permeability significantly influence the wearer's thermal sensation, humidity sensation, and comfort sensation. The sample materials in this study are all for spring/fall and summer seasons; therefore, their air permeability and moisture regain can be lacking for optimal wear sensation during summer working conditions. Out of all four samples, S2 seemed to be the most superior in wear comfort, followed by S1 which scored similarly except for moisture regain. S3 had the lowest air permeability and low moisture regain with a high potential to cause discomfort due to hotness and humidity.

The survey conducted on workers with experience wearing safety clothing made of S1 material indicated that the main reasons for its dissatisfactory wearing experience were hotness and humidity (Park 2018). Natural persimmon juice dyeing was suggested to mitigate weaknesses by increasing air permeability, moisture regain, and water vapor permeability of the S1 fabric. Therefore, for further discussion of the study results, immature persimmon juice dye was subsequently applied to S1 fabric and the effect of persimmon juice dyeing was determined through a comparative analysis. By setting the larger value as 100%, the moisture regain ratio of undyed to dyed fabric was 2.21% (77.3%): 2.86% (100.0%), showing more than 20% increase; similarly the air permeability ratio of undyed to dyed fabric was 41.7 (100.0%): 39.6 (95.0%). Finally, water vapor permeability was slightly elevated from 9708 (92.8%) to 10,468 (100.0%) after dyeing. Persimmon juice dyeing increased fabric moisture regain by 22.7% and water vapor permeability by 7.2%. This result follows previous studies where the dyeing of cotton and rayon fabric with persimmon juice increased the moisture regain and water vapor permeability as well as micro-humidity within the experimental clothing worn by the test subject (Ko and Lee 2003; Park 2012; Park and Kang 2014; Park and Son 1999). Thus, it is evident that the wear comfort for S1 can be significantly enhanced through a natural dyeing method using persimmon juice. In this study, the air permeability decrease of 5.0% was due to the highly dense warp count of S1 compared to rayon and cotton used in the former study. However, a prior study indicated that persimmon juice dyeing increased the air permeability of cotton, rayon, and silk fabric (Park and Park 1998). The natural dyeing process in this study (dip dyeing in a 2:1 mixture of water: persimmon juice) and drying in the sunlight after washing is compatible with sustainable development and evolving global standards for environmentally friendly practices in the field of textiles and clothing.

An effective release of heat and moisture of the micro-climate in hot conditions is associated with comfort; however, it causes discomfort when water remains in the micro-climate between clothes and skin. Therefore, it is necessary to research ways to improve moisture absorption characteristics due to water vapor permeability and moisture transportation are directly related to wear comfort.

Table 2 Comparison of properties of fluorescent fabric samples

Measurement items	**Fabrics**				
	Measuring direction	**Samples**			
		S1	**S2**	**S3**	**S4**
Air permeability (mm/s)		182	179	37.3	129.6
Moisture regain (%)		0.53	1.11	0.10	0.06
Water vapor permeability (g/m^2 24 h)		8998	10,885	9634	10,705
Tensile					
Strength (N)	Warp	660	690	640	480
	Weft	740	360	290	330
Elongation (%)	Warp	36.2	20.5	13.1	27.3
	Weft	27.8	18.2	55.2	26.1
Abrasion (times)		Above 20,000	Above 20,000	15,300	Above 20,000
Rate of size change after washing (%)	Warp	− 1.0	− 1.5	− 1.0	− 0.5
	Weft	− 1.0	− 1.0	− 0.5	− 0.5

S1: T company fluorescent fabric (manufactured in Korea)

S2: T company fluorescent fabric (manufactured in Japan)

S3: Trial fluorescent fabric for adults (purchased in Dongdaemun market, Seoul; random)

S4: Trial fluorescent fabric for children (purchased in Dongdaemun, market, Seoul; random)

Tensile strength and elongation

Tensile strength and elongation refers to durability and resilience due to external forces and is one of the characteristics that restrains human motion during the wearing of clothing (Kim et al. 2000; Ko and Lee 2003). Table 2 shows the tensile strength measurements of warp and weft directions. Tensile strength in the warp direction was similar for S1, S2, and S3, but lower in S4. In the weft direction, tensile strength ranked S1 > S2 ≥ S4 ≥ S3, and S1 had a tensile strength that is 2–2.5 times greater than the other three samples. Elongation showed a distinct difference between warp and weft directions, and S1 displayed the best warp elongation and S3 the best weft elongation. Additionally, S3 showed the biggest difference between warp and weft elongation.

Abrasion

Abrasion strength of S1, S2, and S4 were all above 20,000 and satisfied the general expectation level. However, abrasion strength of S3 was less than 15,300 and denoted poor durability (Table 2).

Rate of size change after washing

The rate of size change after washing the four samples fell within 1–1.5% shrinkage in the warp direction and 0.5–1.0% shrinkage in the weft direction, but the results were not influenced by washing five times (Table 2).

Colorfastness

Table 3 shows that the washing, dry-cleaning, friction, acid and alkali compound, and dry and wet hot-pressing colorfastness were excellent in all four samples, scoring between Grades 4 and Grade 5 (not shown in Table 3). The sunlight fastness was above Grade 4 in all samples and there was no difference observed between the samples. In addition, all the contaminated pieces appeared to have Grade 4 and Grade 5

Table 3 Colorfastness of 4 sample fabrics on washing, dry-cleaning, friction, sunlight, compound (sweat + sunlight), and hot-pressing

Condition colorfastness	Measuring			
	Samples			
	S1	S2	S3	S4
Washing	4–5	4–5	4–5	4–5
Dry-cleaning	4–5	4–5	4–5	4–5
Friction	4–5	4–5	4–5	4–5
Sunlight	Above 4	Above 4	Above 4	4
Compound				
Acid	4–5	4–5	4–5	4–5
Alkali	4–5	4–5	4–5	4–5
Hot-pressing				
Immediately after drying	4–5	4–5	4–5	4–5
4 h after drying	4–5	4–5	4–5	4–5
Immediately after wetting	4–5	4–5	4–5	4–5
4 h after wetting	4–5	4–5	4–5	4–5

in the washing and dry-cleaning fastness and indicated that dye transfer stains did not occur.

From all results of above 7 physical characteristics, it was found that S1 (a Korean material) has a higher possibility of complying with ISO standards, except that the moisture regain is relatively lower than S2. Therefore, it is recommended to increase the mixing ratio of cotton fiber, which is absorbent and also comfortable, in S1 to more than 10% or surface finishing. However, S3 appeared to be lacking air permeability, moisture regain, and abrasion strength; S4 lacked moisture regain, air permeability and tensile strength.

Retroreflective materials

(1) Surface shape Figure 2 shows SEM photos of the surface (a) and cross-section (b) of each sample. R1 and R4 are glass bead-types while R2 and R3 are prism-types. A comparison of R1 and R4 shows that bigger and more homogeneous beads improve retroreflection (Kang and Choi 2016). There is an industrial trend toward prism-types due to their better retroreflection in rain (Park and Choi 2018).

(2) Chromaticity/luminance Luminance (cd/m^2) is the luminous intensity (cd) per unit of area of a light travelling in a particular direction. Luminance varies depending on observation angle and if under a constant light source; in addition, a more reflective object results in a higher luminance intensity (Smith 2000; Yang and Lee 2011; Ji et al. 2008).

Table 4 shows the chromaticity/luminance measurements of the four materials tested in this study. Luminance was measured at 5 cm intervals using an instrument with a measuring diameter of 5 mm. Out of all four samples, R1 and R2 showed similar results; R3 had a luminance factor of 0.09, being the lowest. Therefore, luminance ranked in the order of R4 > R2 ≥ R1 > R3.

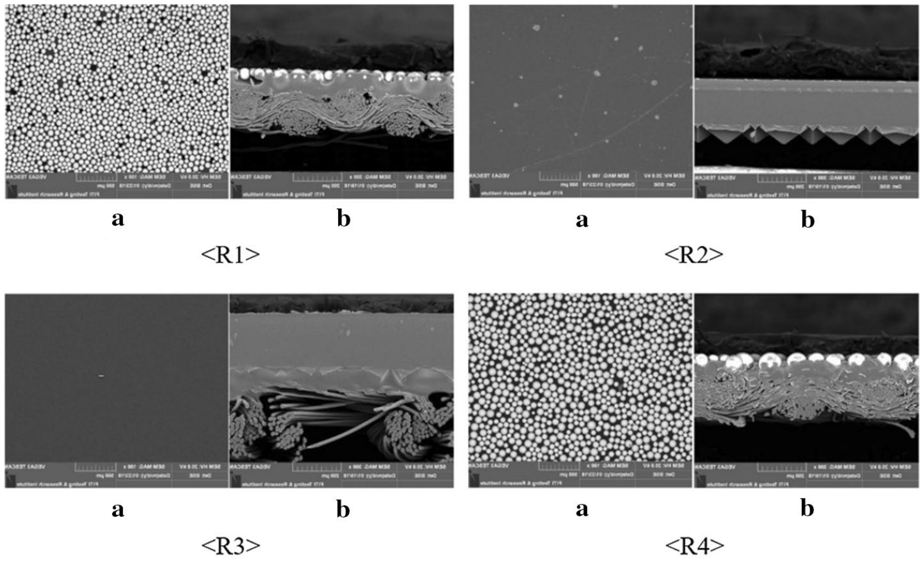

Fig. 2 Morphologies of SEM photos of surface (**a**) and cross-section (**b**) for each sample

Table 4 Chromaticity measurement values of the 4 samples

	R1	R2	R3	R4
Luminance factor	0.16	0.17	0.09	0.21
Coordinate *x*	0.311 2	0.310 7	0.299 4	0.311 0
Coordinate *y*	0.329 1	0.330 4	0.323 5	0.329 1

CIE-D65, 2°, 45/0 method using Black Underlay. Device: Spectrophotometer CM-2500c (Konica Minolta)

ISO 20471 specifies fluorescent fabric colors; however, there is no standard for coloring retroreflective materials. Table 4 indicates the coordinate x and y values for the color of the retroreflective materials. For coordinate x, a higher value denotes red color and lower value denotes green color. For coordinate y, a higher value denotes yellow color and lower value denotes blue color. However, the values are only descriptive of the colors and have no relation with reflective performance.

(3) General retroreflective properties The observation angle is the angle at which the light enters the driver's eyes from a light source that is reflected by a road sign or other objects with retroreflective materials attached. Incidence angle is the angle between the light source and the normal line of a road sign, which distinguishes vehicles in the first and fourth lane, or vehicles closer and further from the road sign.

The general reflective property values shown in Table 5 indicate the intensity of the light entering the driver's eyes after being reflected by a retroreflective surface of a road sign and warning clothing. The angles of 0° and 12′ are important because they correspond to light that effects the driver the most. The larger the observation angle is, the higher the driver is situated above ground; 1°30′ represents the angle of light observed by the driver of a larger vehicle such as cargo truck. $\varepsilon = 90°$ indicates light hitting the observer from the side. All measurements were in compliance with ISO 20471 (2013). ISO 20471 shows that the minimum satisfactory retroreflection factor for one of the two orientations $\varepsilon = 0°$ or $\varepsilon = 90°$ is 75% (for example, at 12′ and 5°) if the factor is greater than 250, which is approximately 75% of 330. The four samples tested in this study all passed this score.

The samples R1 (3M material) and R4 both had relatively consistent results and less deviation in regards to the changing angles; the deviation values ranked in the order of $R3 > R2 \geq R1 \geq R4$. R3's deviation was the greatest and higher than R2 (despite the same manufacturer) due to the presence/absence of patterns. R3 (a directional material) showed measurements that varied the most between $\varepsilon = 0°$ and $\varepsilon = 90°$, and it resulted in the poorest retroreflective properties among all samples at an observation angle of 1°30′ and may not be adequately visible to drivers in vehicles such as trucks.

Table 6 shows the retroreflective property measurements of the four samples after exposure to 5 conditions (abrasion, bending, bending at low temperature, temperature change, and washing 5 times) at an observation angle of 12′ (0.2°) and incidence angle of 5°. Bigger numbers represent better retroreflective properties, and R3; in addition, the prism-type plain sample made by 'R' company showed the highest deviation while also displaying the highest numbers. However, R1 which is a 3M product sample had the steadiest results with the smallest deviation among conditions. R1, a global

Table 5 General retroreflective property values measured at 0° (frontal light) and 90° (lateral light)

	Observation angle	Incidence angle	Retroreflective property (cd/lx m^2)			
			R1	R2	R3	R4
$\varepsilon = 0°$	12′	5°	473.3	411.9	1009.5	550.7
		20°	463.6	315.4	810.3	559.4
		30°	418.0	271.4	557.8	528.1
		40°	287.8	145.5	302.0	475.5
	20′	5°	334.6	463.7	576.0	346.7
		20°	329.0	245.9	469.6	344.8
		30°	311.8	161.5	337.6	325.3
		40°	238.0	90.8	196.5	298.8
	1°	5°	46.0	76.7	70.9	41.6
		20°	46.5	51.6	61.3	48.4
		30°	38.4	53.3	51.4	57.4
		40°	24.8	19.6	33.0	48.6
	1°30′	5°	22.2	25.1	10.33	16.0
		20°	21.8	17.6	10.6	16.8
		30°	22.5	17.0	12.9	17.3
		40°	17.3	15.7	12.2	15.1
$\varepsilon = 90°$	12′	5°	471.0	383.5	746.1	446.4
		20°	438.3	312.5	525.5	532.6
		30°	332.3	273.9	369.4	522.3
		40°	191.1	140.0	238.4	466.6
	20′	5°	331.8	404.35	366.7	287.6
		20°	321.6	228.3	221.0	324.6
		30°	266.5	155.7	153.6	318.5
		40°	166.7	86.5	118.4	292.0
	1°	5°	4536	91.1	24.2	40.1
		20°	44.6	60.0	29.8	39.2
		30°	28.9	52.4	32.8	57.5
		40°	36.6	19.3	15.4	56.3
	1°30′	5°	22.4	26.8	18.2	16.6
		20°	20.7	19.4	9.2	16.3
		30°	24.8	20.5	8.7	18.8
		40°	9.9	13.5	9.6	16.7

Table 6 Retroreflective properties at 12′ (0.2°) observation angle and 5° incidence angle after 5 conditions

	Observation angle	Incidence angle	Retroreflective property (cd/lx m^2)			
			R1	R2	R3	R4
Condition 1	12′	5°	436.8	319.6	799.4	390.1
Condition 2			433.0	343.0	822.9	418.1
Condition 3			444.4	350.1	834.1	431.6
Condition 4			450.1	361.9	859.3	450.6
Condition 5			363.1	283.3	686.4	277.8

manufacturer occupying 45% of the world use (Kang and Choi 2016), can be considered the basis for a comparative assessment. Thus, assuming R1's results as the basis for comparison (100%), the other samples ranged between 81.4 and 158.4%. Subsequently, R3 showed the largest deviation.

The plain retroreflective material (R3) in comparison to rectangular material (R2) (Reflomax 2018) is concerned inferior in empirical evaluations in terms of reflecting lateral light and under rainy conditions. This study found that R3's visibility for children's clothing was higher than R2 in a bright setting; however, it was lower in a darker environment. For this reason, prism-type rectangular-patterned material is currently used in police uniforms despite the cheaper price of plain material.

The four types of retroreflective material samples tested in this study were ISO 20471 compliant in terms of general criteria and after exposure to the five conditions. R2 and R3 also passed ISO 20471 certification. Currently available materials made in Korea also have viable quality.

Conclusion

This study comparatively analyzed different fluorescent fabrics and retroreflective material samples for their level of compliance to ISO standards in order to develop safety clothing for road traffic workers and pedestrians that fulfills visibility and wear comfort at the international level.

For fluorescent fabrics, a Korea made sample (S1) currently used in the public sector was compared to an ISO-compliant Japan made sample (S2), a randomly selected sample for adult clothing (S3), and another random sample for children's clothing (S4) manufactured by two different Korean companies. In addition, for retroreflective material samples, a rectangular-pattern type (R2), a plain-type (R3), and a random (R4) Korea made sample were compared to a US made plain-type sample (R1).

First, when comparing the air permeability against the ISO-compliant S2, S1 scored similarly; however, S4 scored 72.4% and S3 was the lowest at 20.8%. Moisture regain ranked in order $S2 > S1 > S3 \geq S4$ indicated that domestically manufactured fabrics lagged behind foreign made products (S2). Water vapor permeability ranked $S2 \geq S4 > S3 > S1$; however, the difference was minor and all other fabrics fell within 82.7–98.3% compared to S2. Second, tensile strength in the warp direction was similar for S1, S2, and S3; however, the lowest was in S4. In the weft direction, tensile strength ranked $S1 > S2 \geq S4 \geq S3$ from strongest to weakest. Elongation showed distinct differences for both warp and weft directions. Abrasion strength was satisfactory in S1, S2, and S4, but not in S3. Size change after washing was not affected in all samples for both warp and weft directions. Third, colorfastness was good for all samples under washing, dry-cleaning, friction, compound, and hot-press conditions, from 4 to 5 level. Colorfastness to sunlight, light and perspiration for all four samples were 4 and above, with little to no difference. Fourth, chromaticity/luminance of two bead-type (R1 and R4) and two prism-type (R2 and R3) retroreflective materials were ranked in order of $R4 > R2 \geq R1 > R3$. Fifth, the four types of retroreflective material samples tested in this study were compliant with ISO 20471 in terms of general criteria and after exposure to five conditions.

The fluorescent fabric S1 (made in Korea) could meet ISO 20471 standards if the moisture regain is improved; therefore, a mixing ratio of cotton fiber of at least 10% or surface finishing is recommended. However, S3 lacked in terms of air permeability, moisture regain, and abrasion strength, and S4 lacked moisture regain, and slightly lacked air permeability and tensile strength. As for retroreflective materials, all of the tested samples satisfied the international criteria in terms of general and post-exposure retroreflective properties under the 5 conditions.

A limitation of the study is that the relation between the physical performance of the sample materials and the actual subjective evaluation of wear comfort was not established. Therefore, using the materials that were finally selected, a test warning clothing will be developed and tested on sweating manikins or human subjects in an additional study.

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Authors' contributions
SP, as the only author, designed and conducted the research, collected and analyzed the data and drafted the manuscript, and contributed to the writing and improvement of the manuscript. The author read and approved the final manuscript.

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Availability of data and materials
All data generated or analyzed during this study are included in this manuscript.

Competing interests
The author declares that she has no competing interests.

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