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Comparative Study of Chinese and International Standard Systems on Chemical Protective Clothing

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Abstract

Through the comparative analysis of China's national and international standard systems on chemical protective clothing (CPC), this paper summarizes the differences in classification and minimum performance requirements between several standard systems. The study provides the most basic performance assessment factors for all types of CPC. It can also be observed that the standard systems of European Standards (EN) and the International Organization for Standardization (ISO) have similar classifications and performance requirements for CPC, while China's standard systems (GB) mainly give detailed requirements for emergency team CPC as a supplement for previous international standards.

Keywords: Chemical Protective Clothing; Standard; Classification; Performance

1 Introduction

Personal protective equipment (PPE) [1] is specially designed to protect employees from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, mechanical, electrical, or other workplace hazards. Chemical protective clothing (CPC) [2-5] is a type of PPE that protects people from chemical-related injuries in their occupational activities. It was not until 1971 that the U.S. Occupational Safety & Health Administration (OSHA) established basic personal protective apparel standards for industry. Therefore for many years, workers were left to their own devices for defense against chemical or biological hazards. Later on, the National Institute for Occupational Safety and Health (NIOSH), the National Fire Protection Association (NFPA), and various industry safety equipment associations joined in [6]. The development, manufacture, and authentication of CPC center on the developed countries and international organizations in Europe and America. These countries and regions were the first to develop CPC, so the standards they have established are relatively well developed. Currently, NFPA standards, European standards (EN), and International Organization for Standardization

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(ISO) standards are the main CPC standards in the world. China did not release its standards for CPC until 2009.

CPC has been widely used in fields such as heavy industry, fire fighting, national defense, and medicine. However, standards for CPC vary greatly due to differences in countries' approaches to formulating such standards, including testing methods and the factors considered during product performance evaluations. This paper summarizes China's national and international standard systems for CPC through a comparative analysis of the standards' different factors for performance control in an attempt to provide a foundation for China's reform on CPC and to improve China's overall standardization levels.

2 Methodology

This study selected 44 standards [7-50] within six standard systems for CPC (as shown in Table 1) as the subjects, which were provided by the General Logistics Department, China Armed Forces. The comparative study of these standards involved the following aspects: (1) analysis of release dates of CPC standards in different standard systems; (2) analysis of classification of CPC in different standard systems; (3) analysis of performance factors for CPC in different standard systems to obtain the assessment factors with relatively high weights; and (4) analysis of minimum performance requirements for CPC in different standard systems.

The standards used in this study involve six standard systems. They are the American Society for Testing and Materials (ASTM) standards, EN standards, British Standards (BS), ISO standards, Japanese Industrial Standards (JIS) and China standards (GB). These standard systems and their serial numbers are as shown in Table 1, while the distribution of the standards is shown in Fig. 1. ASTM and EN have the larger share of standards (at 14 and 11, respectively), followed in descending order by nine ISO standards, five JIS standards, four GB standards, and one BS standard.

All these standards encompass testing methods for CPC's protection performance against chemicals, as well as CPC's classification, performance requirements, selection, usage, and maintenance. Table 2 provides detailed information about these standards and the standard organizations.

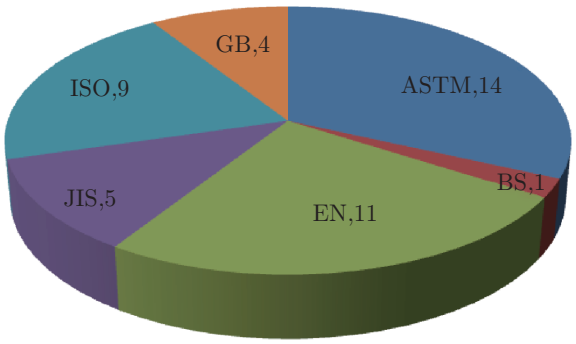


Fig. 1: Distribution of standards for CPC analyzed in the study

Table 1: List of standards for CPC used in the study

Standard system	Content	Serial number for standards
ASTM	Testing Methods	ASTM F1407-99a (2006); ASTM F1001-99a (2006); ASTM F903-03 (2004); ASTM F1383-07; ASTM F2130-01; ASTM F1359-07; ASTM F1383-11
	Performance Requirements	ASTM F2053-00 (2006); ASTM F1461-07; ASTM F2061-08; ASTM F1296-08
	Others	ASTM F1194-99 (2005); ASTM F1194-99 (2010); ASTM F2669-09
BS	Performance Requirements	BS 8428-2004
EN	Testing Methods	BS EN 14786: 2006; BS EN 14325: 2004; BS EN 13595-4: 2002; BS EN 1621-2: 2003; BS EN 468: 1995; BS EN 463: 1995; BS EN 464: 1994
	Performance Requirements	BS EN 14605: 2005; BS EN 13034: 2005; BS EN 943-2: 2002; BS EN 943-1: 2002
JIS	Testing Methods	JIS T8030-2005; JIS T8032-2005; JIS T8031-2010; JIS T8061-2010
	Performance Requirements	JIS T8115-2010
ISO	Testing Methods	ISO 13994: 2005; ISO 17491: 2002; ISO 13982-2: 2004; ISO 6529: 2001; ISO 6530: 2005; ISO 22608: 2004
	Performance Requirements	ISO 16602: 2007; ISO 13982-1: 2004; ISO 27065: 2011
GB	Testing Methods	GB/T 23462-2009; GB/T 24540-2009
	Performance Requirements	GB/T 24539-2009; GB/T 24540-2009; GB/T 24536-2009

Note: EN refers to European standards, and BS represents the standards formulated by the British Standards Institution (BSI). However, as a member state of the European Union, Britain often takes the EN standards as its own. Therefore, in the list, BS EN is equivalent to EN.

3 Result and Discussion

3.1 Analysis of Release Dates of Standards on CPC in Different Standard Systems

The 44 standards in Table 1 were analyzed according to year of release. The result, as shown in Fig. 2, indicates the majority of international standards analyzed in the study were released mainly during 2004-2005, with a greater number in 2005. In contrast, China did not release its standards for CPC until 2009, with the introduction of GB/T 24539-2009 *Protective clothing—Performance requirements of chemical protective clothing* [38], GB/T 24536-2009 *Protective clothing—Selection, use and maintenance of chemical protective clothing* [39], GB/T 24540-2009 *Protective clothing—Protective clothing against liquid acids and alkalis* [40], and GB/T 23462-2009 *Protective clothing—Test method for chemical protective materials to permeation by chemicals* [41].

Table 2: Different standard systems for CPC

Name of standard system	Organization for formulating standards	Year founded	Description
American Society for Testing and Materials (ASTM)	The American Society for Testing and Materials (ASTM)	1898	ASTM is one of the world's largest standardization organizations to develop voluntary consensus technical standards, and one of the oldest nonprofit academic bodies on standardization in the U.S.
European Standards (EN)	The European Committee for Standardization; French: Comité Européen de Normalisation (CEN)	1961	Based on the German standard system DIN and British BS, EN represents the world's most advanced and rigorous standard system.
British Standard (BS)	British Standards Institution (BSI)	1901	The earliest national standardization body in the world.
International Organization for Standardization (ISO)	International Organization for Standardization (ISO)	1947	ISO is the world's largest developer of voluntary international standards with 140 member countries.
Japanese Industrial Standard (JIS)	Japanese Industrial Standards Committee (JISC)	1921	JIS is the most important and authoritative national standard system in Japan.
China's Guo Biao (GB)	Standardization Administration of the People's Republic of China	1957	GB is China's national standard system. GB standards can be divided into compulsory (GB) standards and recommendatory (GB/T) standards.

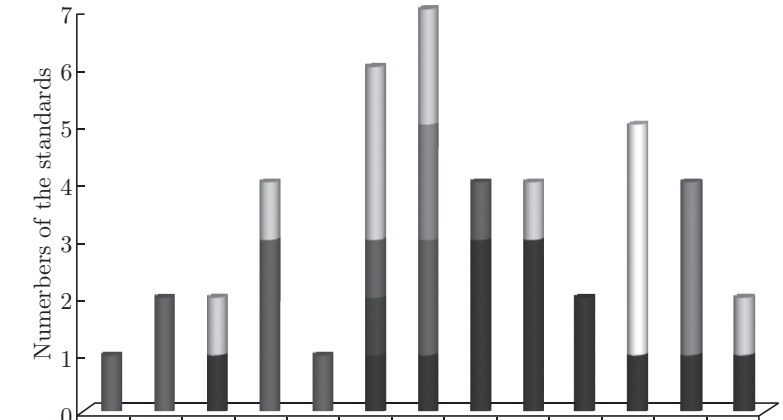
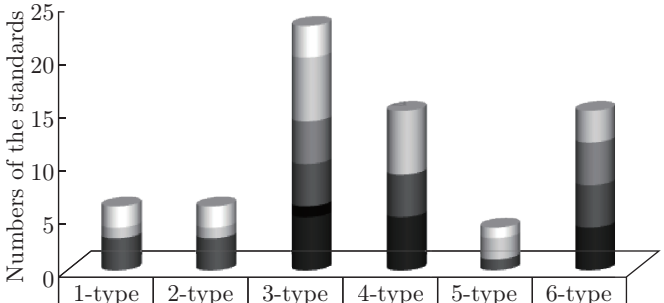


Fig. 2: Release date of standards for CPC analyzed in the study

3.2 Classification of CPC in Different Standard Systems

The six standard systems shown in Table 1 use different methods to classify CPC. Among them, EN and ISO standards classify CPC into six categories, though EN standards add a sub-type for emergency teams (ET). GB standards are based mainly on ISO 16602: 2002, classify CPC into four categories, and further subdivide type 2 non-gas-tight protective suits and type 3 liquid-tight protective suits with the addition of the new ET sub-type. Table 3 lists the classification of standards according to the six types of CPC and gives the secondary and tertiary classification. The serial numbers corresponding to each type of CPC are also shown in Table 3. Fig. 3 presents a statistical analysis of the relationship between protective clothing types and the numbers of the corresponding standards. Fig. 4 shows the configurations of the SCBA (self-contained breathing apparatus) both inside and outside the CPC.



	1-type	2-type	3-type	4-type	5-type	6-type
GB	2	2	3	0	1	0
ISO	1	1	6	6	2	3
JIS	0	0	4	0	0	4
BSEN	3	3	4	4	1	4
BS	0	0	1	0	0	0
ASTM	0	0	5	5	0	4

Classification of chemical protective clothing

Fig. 3: Classification and distribution of selected standards in terms of classification of CPC

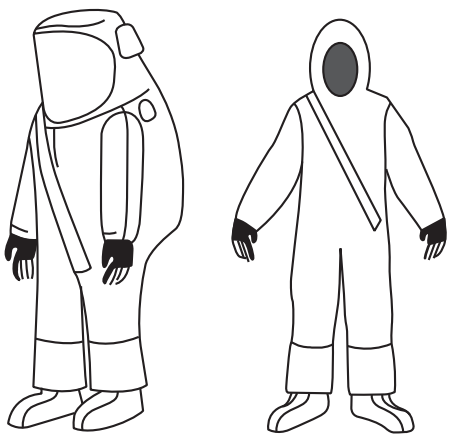
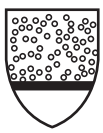


Fig. 4: SCBA inside (left) and outside (right) for CPC

Table 3: Classification of CPC

Diagram	Secondary classification	Tertiary classification	Serial number for standards
	Type 1: "Gas-tight" chemical protective suit	Type 1a: with SCBA inside the protective suit Type 1b: with SCBA outside the protective suit Type c: with an external source of breathable air providing positive pressure inside the suit	BS EN 943-1: 2002; ISO 16602: 2007; BS EN 14325: 2004
		Type 1a-ET: for emergency teams Type 1b-ET: for emergency teams	BS EN 943-2: 2002; GB/T 24539-2009; GB/T 23462-2009
	Type 2: "Non-gas-tight" chemical protective suit		BS EN 943-1: 2002; BS EN 943-2: 2002; ISO 16602: 2007; BS EN 14325: 2004; GB/T 24539-2009; GB/T 23462-2009
	Type 3: "Liquid-tight" chemical protective clothing	Type 3a: with SCBA inside the protective suit Type 3b: with SCBA inside the protective suit	BS 8428-2004; BS EN 468: 1995; BS EN 14325: 2004; BS EN 14605: 2005; BS EN 14786: 2006; ISO 16602: 2007; ISO 17491: 2002; ISO 13994: 2005; ISO 6529: 2001; ISO 6530: 2005; ISO 22608: 2004; ASTM F1383-07; ASTM F1407-99a (2006); ASTM F1383-11; ASTM F2130-01; ASTM F1359-07; JIS T8030-2005; JIS T8032-2005; JIS T8031-2010; JIS T8061-2010; GB/T 24539-2009; GB/T 24540-2009; GB/T 23462-2009;
		Type 3a-ET: for emergency teams	GB/T 24539-2009; GB/T 24540-2009; GB/T 23462-2009
	Type 4: "Spray-tight" chemical protective clothing		BS EN 14325: 2004; BS EN 14786: 2006; BS EN 468: 1995; BS EN 14605: 2005; ISO 6530: 2005; ISO 16602: 2007; ISO 13994: 2005; ISO 22608: 2004; ISO 6529: 2001; ISO 17491: 2002; ASTM F1383-07; ASTM F1383-2011; ASTM F1359-07; ASTM F1407-99a (2006); ASTM F2130-01
	Type 5: Chemical protective clothing providing protection against airborne solid chemicals		BS EN 14325: 2004; ISO 16602: 2007; ISO 13982-1: 2004; GB/T 24539-2009
	Type 6: Chemical protective clothing with "limited protective performance against liquid chemicals"		BS EN 13034: 2005; BS EN 14325: 2004; ISO 16602: 2007; BS EN 468: 1995; BS EN 14786: 2006; ASTM F1383-11; ISO 6529: 2001; ISO 17491: 2002; ASTM F1383-07; JIS T8032-2005; ASTM F1359-07; ASTM F1407-99a (2006); JIS T8030-2005; JIS T8031-2010; JIS T8061-2010

*Note: SCBA refers to self-contained breathing apparatus.

3.3 Performance Assessment Factors for CPC in Different Standard Systems

This section presents a comparison of performance assessment factors in different standard systems for the six types of CPC. Among the standards in Table 1, the study compares those that have performance requirements. ASTM and JIS standards, which concentrate mostly on test methods for resistance to permeation and how to wear and maintain CPC, do not list any specifications for performance and therefore are not discussed. To clearly distinguish assessment factors in different standard systems, the study uses different symbols to represent different standards (see Table 4). In Table 5, a comparison of performance assessment factors is shown using the symbols in Table 4 to represent different serial numbers.

Table 4: Specification of symbols for different standards

BS	EN	ISO	GB
△ BS 8428-2004	◯ BS EN 14605: 2005	■ ISO 16602: 2007	★GB/T 24539-2009
	◎ BS EN 13034: 2005	□ ISO 13982-2: 2004	☆GB/T 24540-2009
	⊙ BS EN 14325: 2004		
	⊕ BS EN 943-2: 2002		
	• BS EN 943-1: 2002		

Table 5 also shows the types of protective clothing and performance assessment factors covered by the selected standards. Based on the number of symbols, it can be observed that the corresponding standards for all types of CPC list requirements for such performance assessment factors as tensile strength, trapezoidal tear resistance, puncture resistance, bursting resistance, abrasion resistance, flex cracking resistance, flex cracking resistance at low temperatures (−30°C), and resistance to permeation by liquids/gaseous chemicals (except type 5). Therefore, we can conclude that these performance factors are the most basic for CPC. The EN and ISO standards contain additional assessment factors. Type 1 and type 2 CPC encompass more assessment factors and are covered by more standards. GB standards primarily provide performance requirements for ET CPC.

3.4 Analysis of Minimum Performance Requirements for CPC in Different Standard Systems

Among all the performance assessment factors for CPC listed in Table 5, the minimum performance requirements are different in different standard systems. A comparative analysis of major performance factors is given as follows:

1) Seam strength: This performance assessment factor is required for all six types of CPC. The EN standards for type 4 and type 6 protective clothing specify a seam strength $\geq$ class 1 (above 30 N); other types of protective clothing with requirements for the performance (see Table 5) specify a seam strength $\geq$ class 5 (above 300 N). The ISO standards for type 5 chemical protective clothing specify a seam strength $\geq$ class 1 (above 30 N). The GB standards for type 3 protective clothing against liquid acids and alkalis require a seam strength $\geq$ 98 N, and for other protective clothing a seam strength $\geq$ 45 N. The ISO standards do not list any specific requirement for this performance.

2) Leakage: Among the six types of CPC, only type 1 and 2 have requirements for leakage performance (see Table 5). The EN standards require that the pressure drop shall not be greater than 300 Pa (3 mbar) in 6 min. The ISO standards specify a pressure drop $\leq$ 20%. The GB standards for type 1-ET protective clothing require pressure in suit $\geq$ 80% of test pressure.

3) Inward leakage: The ISO standards require that inward leakage shall be not greater than 0.05%. The EN standards do not have any requirement for type 1a and type 1b protective clothing on inward leakage, and specify the same requirement for type 1c as the ISO standards. The EN standards for type 5 and type 6 CPC require an inward leakage rate of 1.0 μg/(cm^2*min). The GB standards for type 1-ET protective clothing require that no leakage should occur 1 h after liquid jet test, and for type 2-ET protective clothing no leakage should occur 20 min after jet test.

Table 5: Performance assessment factors for different types of CPC in different standard systems

Performance assessment factors	Type 1							Type 2			Type 3							Type 4		Type 5			Type 6	
	Type 1a		Type 1b		Type 1c		1-ET	2		2-ET	3a		3a-ET	3b										
	EN	ISO	EN	ISO	EN	ISO	GB	EN	ISO	GB	BS	GB	GB	BS	EN	ISO	GB	EN	ISO	EN	ISO	GB	EN	ISO
Seam strength	●⊕	×	●⊕	×	●	×	×	●	×	×	△	☆	☆	△	◯	×	☆	◯	×	×	□	×	◎	×
Leakage	●	■	●	■	●	■	★	●	■	★	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Inward leakage	●	×	●	■	●	■	★	●	■	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Resistance to penetration by liquids (jet test)	×	×	×	×	×	×	×	×	×	×	×	★	★	×	×	■	×	×	■	×	×	×	×	×
Resistance to penetration by liquids (spray test)	×	×	×	×	×	×	×	×	×	×	×	★	★	×	×	×	★	×	×	×	×	×	×	×
Breathing hose and ventilating hose	●	×	●	■	●	■	×	●	■	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Air flow rate	●	×	●	×	●	■	×	●	■	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Exhaust assembly	●	■	●	■	●	■	×	●	■	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Pressure in suit	●	■	●	■	●	■	×	●	■	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Resistance to permeation (by liquids/gaseous chemicals)	⊙	■	⊙	■	×	⊙	★	⊙	■	★	△	★	★	△	◯⊙	■	★	⊙◯	■	×	×	×	⊙	×
Resistance to penetration by liquid under pressure	×	×	×	×	×	×	★	×	×	★	×	★	★	×	×	×	×	×	×	×	×	×	×	×
Particulate penetration resistance	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	★	×	×
Resistance to penetration by liquids	×	×	×	×	×	×	×	×	×	×	△	×	×	△	◯	■	×	×	■	×	×	×	◎	■
Liquid repellency	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	★	×	×	×	×	×	◎	■
Tensile strength	●⊕	■	●⊕	■	●	■	★	●	■	★	△	★	★	△	◯	■	★	◯	■	×	×	★	◎	■
Trapezoidal tear resistance	●⊕	■	●⊕	■	●	■	★	●	■	★	△	★	★	△	◯	■	★	◯	■	×	□	★	◎	■
Puncture resistance	●⊕	■	●⊕	■	●	■	★	●	■	★	△	★	★	△	◯	■	★	◯	■	×	□	★	◎	■
Bursting resistance	×	■	×	×	×	■	×	×	■	×	×	×	×	×	◯	■	×	×	■	×	□	×	×	■
Abrasion resistance	●⊕⊙	■	●⊕⊙	■	●⊙	■	★	●⊙	■	★	△	★	★	△	◯⊙	■	★	⊙◯	■	⊙	□	★	◎⊙	■
Flex cracking resistance	●⊕⊙	■	●⊕⊙	■	●⊕⊙	■	★	●⊙	■	★	△	★	★	△	◯⊙	■	★	⊙◯	■	⊙	□	★	⊙	■
Flex cracking resistance at low temperatures (−30°C)	●⊕⊙	■	●⊕⊙	■	●⊕⊙	■	×	●⊙	■	×	△	×	×	△	◯⊙	■	×	⊙◯	■	⊙	×	×	⊙	■
Resistance to ignition	●⊙	×	●⊙	×	●⊕⊙	×	×	●⊙	■	×	△	×	×	△	◯⊙	×	×	⊙◯	×	⊙	×	×	◎⊙	×
Resistance to flame	●⊕⊙	×	●⊕⊙	×	●⊕⊙	×	×	●⊙	■	×	△	×	×	△	◯⊙	×	×	⊙	×	⊙	×	×	⊙	×
Conditioning	●⊙	■	●⊙	×	●⊕⊙	×	×	●⊙	×	×	×	×	×	×	◯⊙	×	×	⊙◯	×	⊙	×	×	⊙	×

4) Resistance to penetration by liquids: The EN and ISO standards only set requirements for type 6 regarding performance, which pertains to resistance to penetration by liquids ≥ class 2 and ≥ class 3. The GB standards for type 3a and 3a-ET CPC specify that the total stain area caused by liquid penetration shall be less than three times the total calibrated stain area; GB/T 24540-2009 [40] standards for protective clothing against liquid acids and alkalis require that the penetration time should be more than or equal to 30 min. Other standard systems do not specify requirements for this performance.

5) Exhaust assembly: The EN and ISO standards share the same requirement for this performance assessment factor, namely within 1 min, pressure change should be less than or equal to 100 Pa. GB standards do not list a requirement for this performance.

6) Tensile strength: For type 1a, type 1b, and type 2 protective clothing, the EN standards specify a tensile strength ≥ class 3 (>100 N), and the ISO standards require a tensile strength ≥ class 4 (> 250 N). For type 1c protective clothing, the EN and ISO standards share the same requirement, a tensile strength ≥ class 3 (> 100 N). For type 3 liquid-tight protective clothing, BS standards require that tensile strength should meet class 4; EN standards require a tensile strength ≥ class 1; ISO standards require a tensile strength ≥ class 1 (> 30 N). For type 4 chemical protective clothing, ISO standards require a tensile strength ≥ class 1 (> 30 N). For type 6 protective clothing, EN and ISO standards require a tensile strength ≥ class 1.

7) Trapezoidal tear resistance: EN and ISO require that type 1 and type 2 protective clothing shall achieve at least class 3 performance (> 100 N). For type 3, BS requires that the material shall achieve at least class 3 performance, and EN and ISO require that material shall achieve at least class 1 (10 N). For type 4 chemical protective clothing, EN, ISO and GB require that material shall achieve at least class 1 performance, and GB requires that type 1-ET and type 2-ET shall achieve at least class 3 performance (> 40 N). For type 5 and type 6 chemical protective clothing, EN and ISO require that they shall achieve at least class 1 performance.

8) Puncture resistance: EN and ISO for this performance both require that type 1, type 2, and type 3 protective clothing shall achieve at least class 2 performance (puncture resistance > 10 N), and that type 4, type 5, and type 6 protective clothing shall achieve at least class 1 performance (puncture resistance > 5 N). GB standards require that type 1-ET protective clothing shall achieve at least class 3 (puncture resistance > 50 N), type 2-ET protective clothing shall achieve at least class 2, and type 3 protective clothing shall achieve at least class 1.

9) Abrasion resistance: EN standards for type 1a, type 1b, and type 2 protective clothing require that the used material shall achieve at least class 3 performance (abrasion cycles to specified damage > 500) or pressure difference within 1 min after abrasion shall not exceed 100 Pa, and ISO standards require that the used material shall achieve at least class 4 performance (abrasion cycles to specified damage > 1, 000). EN and ISO standards for type 1c protective clothing share the same requirement that the used material shall achieve at least class 3 performance (abrasion cycles to specified damage > 500). BS requires that type 3 protective clothing shall achieve at least class 4 performance. EN and ISO standards for type 3, type 4, type 5, and type 6 protective clothing require that the used material shall achieve at least class 1 performance (abrasion cycles to specified damage > 10). GB standards require that type 3 protective clothing shall stand at least 100 abrasion cycles to specified damage.

10) Flex cracking resistance: For the six types of CPC, EN and ISO set the same requirement, namely that they shall achieve at least class 1 performance (flexing cycles to specified damage > 1, 000) or the pressure change between unflexed material and flaxed material in 1 min shall not

exceed 0.1 kPa. GB standards specify that type 1-ET and type 2-ET protective clothing shall achieve at least class 4 performance (flexing cycles to specified damage > 15, 000).

11) Flex cracking resistance at low temperatures (−30°C): EN and ISO standards for type 1 and type 2 protective clothing both require that they shall achieve at least class 2 performance (flexing cycles to specified damage > 200), and for type 3 and type 4 protective clothing both require that they shall achieve at least class 1 performance (flexing cycles to specified damage > 100). BS standards require that type 3 protective clothing shall achieve at least class 2 performance (flexing cycles to specified damage > 200). EN standards for type 5 and type 6 protective clothing require that pressure difference in 1 min shall not exceed 100 Pa; ISO requires that type 5 and type 6 shall achieve at least class 1 performance (flexing cycles to specified damage > 100). GB standards do not have any requirement for this performance.

4 Conclusions

Through a comparative analysis of China's national standards and international standard systems for CPC, it can be observed that the most basic performance assessment factors for all types of CPC are tensile strength, trapezoidal tear resistance, puncture resistance, bursting resistance, abrasion resistance, flex cracking resistance, flex cracking resistance at low temperatures (−30°C), and resistance to permeation by liquids/gaseous chemicals (except type 5). The EN and ISO standards include additional assessment factors. But for many performance assessment factors, EN sets higher requirements than ISO. Type 1 and type 2 CPC encompass more assessment factors and are covered by more standards. ASTM and JIS standards do not list any specifications for performance, but instead focus mostly on test methods for resistance to permeation and how to wear and maintain CPC. GB standards for CPC largely were formed by revising and supplementing ISO 16602: 2002. GB standards mainly give detailed requirements for type 1-ET, type 2-ET, type 3a-ET, and type 5 protective clothing, as a supplement to the previous international standards, which seldom mentioned these requirements. However, GB standards do not specify requirements for other types of protective clothing, and moreover they set quite low requirements for some performance items.

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