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Waterproofing Performance Grade Proposal through Standard Test Result Comparison of Self Adhesive Rubberized Asphalt Sheet

Jae-Yong Yoo [1], Soo-Yeon Kim [2] and Sang-Keun Oh [3,*]

1 Department of Architecture, Graduate School, Seoul National University of Science & Technology, Gongneung-ro, Nowon-gu, Seoul 01811, Korea; yjy5525@daum.net
2 Construction Technology Institute, Seoul National University of Science & Technology, Gongneung-ro, Nowon-gu, Seoul 01811, Korea; ksr1115@seoultech.ac.kr
3 School of Architecture, Seoul National University of Science & Technology, 232 Gongneung-ro, Nowon-gu, Seoul 01811, Korea
* Correspondence: ohsang@seoultech.ac.kr

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Abstract: This study reviewed new concept waterproofing performance gradation to respond to the limit of unified single standard performance standard used in each country from the past until now. This study was carried out using the standard test data from 34 products tested and evaluated by Korea's national quality test institution for 2 years (2018~2019) based on national standard specification (KS F 4934, Self-Adhesive Rubberized Asphalt Sheet). Major proposal contents utilized the result values of 9 waterproofing performance evaluation criteria included in the national standard specification. Major study contents and results are as follows. Existing widely used domestic and overseas standard grading (Stanine, Sten Scores, Grade 5 Scale, energy consumption efficiency, and other grading) theories were investigated and analyzed. Based on the analysis contents, standard Grade 5 Scale system suitable for waterproofing material performance grading was selected and applied. Grade sections were set according to the application ratio for each grade section of Grade 5 Scale (grade 1 with 10%, grade 2 with 20%, grade 3 with 40%, grade 4 with 20% and grade 5 with 10%). According to the set sections, performance grades were derived for 9 test criteria of 34 products. Section setting standard for grade section was derived centered on the performance result values of 9 criteria. As a result, average value of waterproofing performance of each of 9 test criteria for 34 products was verified to have 1.2 times to 7.52 times higher performance value than the minimum quality standard (based on grade 5). Such results sufficiently showed the limit of the current unified single standard performance application. Also, as a solution for waterproofing quality degradation problem, possibility to apply the waterproofing performance grading of this study was verified. Therefore, through this study, it is decided that new concept quality standard to pursue future waterproofing industry development can be set, quality reinforcement is possible by performance grading for each product and sustainable waterproofing performance maintaining effect at the waterproofing construction site can be expected with the use of such gradation.

Keywords: Self Adhesive Rubberized Asphalt Sheet; standard test data; waterproofing performance gradation; Korea Standard

1. Introduction

Currently, central keywords reflected to building and civil structure construction can be said to be Manhattanization, long lifespan, bigger and deeper [1]. When you see these in the perspective of design, material, construction and maintenance, construction structure faces harsh environmental

problem (temperature change, snow, rain, wind, water pressure, earth pressure, earthquake, vibration, various service loads, etc.) as one of the problems that must be solved right after completion [2].

Such environmental problem works as a factor to deteriorate concrete structure. Among the deteriorating factors, water leakage that is on the news every day recently as social issue is one of the representative cases [3]. Water leakage occurring in construction structure is recognized as a chronic problem that is not solved yet from the past until now [4].

To solve water leakage problem, all aspects of waterproofing design, waterproofing material, waterproofing construction and waterproofing maintenance [5] must be considered. Especially, waterproofing material performance [6] is one of the performances that are required as mandatory for sustainable long lifespan and high durability construction structure [7]. Therefore, waterproofing material requires high quality complex performance that can respond to various and harsh environment and usage conditions [8] inside and outside the construction structure.

Material used for waterproofing are classified to asphalt, synthetic polymer, inorganic, etc. [9] according to the chemical composition ingredients and can be divided to film, sheet and complex form [10] according to the form.

These waterproofing material are managed by standard such as KS, JIS, ANSI, ASTM, GB, BS, DIN, etc. [11] in each country, and in most standards, minimum quality standard and the test methods [11] are presented for each waterproofing material. This is the quality management method generally applied not only in Korea but also in many countries, and it has contributed greatly to the waterproofing technology development of the past and the present.

But, this is merely a tool to maintain the minimum quality of the corresponding waterproofing material, and in the 21st century, it is difficult to see it as the quality standard [12] that can complexly respond to the requirements demanded in construction structure. That is, with currently unified single minimum quality performance, it cannot be concluded as waterproofing performance suitable for concrete structure part of a construction structure [13].

Considering current waterproofing technology development direction requiring high performance and high quality, existing quality management method still managing only the minimum quality seems to be difficult to secure future sustainable long lifespan and high performance. Also, with unified single quality standard of the corresponding product, it cannot respond to ever changing various requirement performances [14], and there is a limit of difficulty in reinforcement of safe product usage requirements.

Therefore, this proposal intends to review waterproofing performance gradation with KS F 4934 as target among Korea's national standards. Also, it intends to investigate widely used domestic and overseas standard grading systems to verify possibility to apply waterproofing material gradation. For this, total of 3 stages are carried out including stage 1, survey of domestic and overseas standard grading criterion utilization cases, stage 2, collection of the opinions of the experts in standard and waterproofing field and stage 3, proposal of standard grading system to apply to waterproofing performance grading.

Through such study process, it studies the realistic problems of the application to the site only if it satisfies the unified single quality standard specified in the existing national standard. Also, the study intends to review the possibility and effectiveness of the new concept waterproofing performance grading that can also select waterproofing material with high quality performance required for structure with higher requirement for durability and longer life cycle.

2. Survey of Existing Domestic and Overseas Standard Grading System Cases

Existing domestic and overseas standard grading systems were surveyed to verify the possibility to apply to waterproofing performance gradation. As a result, Stanine, Sten Scores, Grade 5 Scale and energy efficiency grading, etc. were surveyed.

Stanine [15] grade is compound of Standard and Nine and it is the criterion to divide the original score distribution into 9 grades. To explain in detail, it refers to the standard score which converted original score distribution to score distribution with average of 5 and standard deviation of 2, and it is

the format to divide to sections and set range by setting highest score to 9 and lowest score to 1 and setting median score which corresponds to average to 5.

Sten Scores [16] defines standard regular distribution as standard to show approximate location (range of value) related to the collected group, and unlike Stanine standard score with median point of 5, Sten Scores can be seen as having median point of 5.5, and it has the characteristics of having no standard value. Sten Scores is, like Stanine, for individual standard score, divided centered on the center of standard deviation, and as the same as Stanine, individual Sten score is also applied with half of standard deviation. Therefore, Sten score of 5 includes all standard scores of −0.5~0, and centered on −0.25, Sten score of 4 includes all standard scores of −1.0~−0.5, and −0.75 becomes the center. Sten score 1 includes all standard scores of −2.0 or less. Sten score refers to 6~10 and "Mirror" score refers to 5~1.

Grade 5 Scale [17] is the method of evaluating academic achievement level for each student in Korea's elementary, middle and high schools. In Korea, it is widely used in all elementary, middle and high schools. Grade 5 Scale's standard score evaluation method is the method of listing the corresponding students' scores in the order and bestowing grade by verifying the rank of the student to evaluate. Basically, it is based on regular distribution, but it is divided to 5 grades and classifies the grades according to the grade ratio (10%, 20%, 40%, 20% and 10%). Grade 5 Scale evaluation method is classified to absolute evaluation and relative evaluation as in the following Table 1.

Table 1. Korea's A, B, C, D and E score grading system gradation details.

Absolute Evaluation Grades		Relative Evaluation Grades	
Score Section	**Grade Index**	**Achievement Rate**	**Grade Index**
90–100	A	10%	A
80–89	B	20%	B
70–79	C	40%	C
60–69	D	20%	D
0–59	E	10%	E

Energy consumption efficiency grading system [18] specifies production and sales of energy saving type product from production stage with material with more energy consumption as target based on Energy Usage Rationalization Act [19], and for consumers to be able to easily identify and purchase energy saving type product, grade label is marked on the product from grade 1 to 5, and system of prohibiting production and sales is used for the products not meeting the minimum consumption efficiency standard.

In addition, there is a grading system to classify the grades of the finish material to incombustible material, flame retardant material and limited incombustible material for the purpose of setting flame retardant performance test method, performance standard and fire expansion prevention structure standard to protect life and property by preventing harmful gas generation and fire expansion, etc. in the material in case of fire in building [20]. As overseas cases, in case of USA, interior finish material's combustibility grades are classified and used as 3 grades (Class A, B and C) [21]. In the study lead by Australia, there is a case of specifying ISO9705:1993(Room Corner Test) with 5 stages grades (A, B, C, D and E) [22] according to Flash Over, Heat Release Rate and smoke generation amount. In case of Europe, in (EN 13823; Single Burning Item; SBI), it specifies 7 grades of A1, A2, B, C, D, E and F [23].

3. Collection of the Opinions of Experts in Standard and Waterproofing Field and Proposal for Application of Waterproofing Material Performance Gradation

With domestic and overseas standard grading criterion surveyed above, Stanine, Sten Scores, Grade 5 Scale and energy efficiency grading, opinions of the experts in Korea's standard and waterproofing field were collected for waterproofing performance gradation application. The opinions were that,

Stanine and Sten Scores methods are the systems required for grade subdivision (9~10 grades) in wide range where many people participate nationwide such as high school academic record grade and college admission exam grade with high school students as target, and if this waterproofing material quality is subdivided to 9~10 grades, in the application at the site, it is decided that there is a big possibility that it will rather cause confusion by subdivision of the grade subdivision.

On the other hand, Grade 5 Scale grading system is decided to be able to prevent unnecessary performance and excessive design in waterproofing performance gradation in the perspective of consumers and to be able to apply 5 grading system for waterproofing design suitable for environment of each structural waterproofing construction part. Also, in energy consumption efficiency 5 grading system, for the corresponding items, it lowers proportion of grade 1 to be less than 10%, and by with gradation to make grade 2 as 20%, grade 3 as 40%, grade 4 as 20% and grade 5 as 10%, it is the standard grading system reflecting the intention to reduce energy consumption by throwing out products not meeting the quality, and it is decided that it will be possible to correspond to waterproofing performance gradation. It also has the expectation in terms of production that 5 grades system can enhance the current problem of hindering technology development by only applying the existing unified quality standard.

According to such opinions, this study intends to "waterproofing performance 5 gradation method" using Grade 5 Scale grade energy efficiency grade system according to the purpose of reinforcing grade standard in waterproofing construction.

4. Standard Test Data Analysis Waterproofing Performance Gradation

4.1. Gradation Target Waterproofing Material

Target material of this study is constructed without using heating tool or adhesive, etc. to prevent inflow of water into the base structure of construction structure. The unique feature is the waterproofing material [24] attached to base material using only the adhesive property of waterproofing material (rubberized asphalt). Waterproofing layer is composed of film waterproofing material made with rubberized asphalt material with self adhesive property, sheet stacked with high density polyethylene film, synthetic polymer sheet, felt and other protective material to protect waterproofing material on the surface and complex film waterproofing material. All products made of film and sheet with such material characteristics are tested and evaluated according to KS F 4934 standard specification. This material's KS F 4934 (Self Adhesive Rubberized Asphalt Sheet) [24] performance standard (basic quality standard) is as in Table 2.

4.2. Gradation Target Performance Evaluation Criteria

This study, among test criteria of Table 3, based on "Grade 5 Scale" theory adopted in 2.2, excluded performance evaluation criteria (curve resistance performance, water pressure resistance performance, sink resistance performance and fatigue resistance performance) by qualitative evaluation (visual observation) inadequate for gradation and implemented gradation analysis on gradation 9 performance evaluation criteria (tensile strength and elongation ratio of tensile performance, tensile strength and elongation ratio of 60 °C temperature dependency performance, tensile strength and elongation ratio of −20 °C temperature dependency performance, peeling resistance performance of adhesion stability performance and adhesion performance) with applicable qualitative evaluation (mechanical measurement). Basic conditions for standard test data analysis are as in the following Table 3.

Table 2. KS F 4934 performance standard.

Performance Criteria			Performance Standard (Basic Quality Standard)	Remark
Tensile performance	Tensile strength (N/mm) Elongation ratio (%)		3.0 or more 200 or more	Quantitative evaluation criteria (7 items)
Tearing performance (N)			25 or more	
Temperature dependency performance	60 °C	Tensile strength (N/mm)	2.0 or more	
		Elongation ratio (%)	150 or more	
	−20 °C	Tensile strength (N/mm)	5.0 or more	
		Elongation ratio (%)	50 or more	
Curve resistance performance			There shall be no fine lines or peeling on protective film or sheet at −20 °C	Qualitative evaluation criteria (Exclude)
Adhesion stability performance		Water pressure resistance performance	There shall be no water penetration	
		Peeling resistance performance (N/mm)	1.5 or more	Quantitative evaluation criteria (2 items)
Adhesion performance (peel-out) (N/mm)			1.5 or more	
Sink resistance performance			There shall be no water penetration after 48 h from fixing	Qualitative evaluation criteria (Exclude)
Fatigue resistance performance			There shall be no fine line or fracture at 20 °C and −20 °C, and it shall not be separated from base surface (1000 times).	

Table 3. Test data analysis conditions for performance gradation.

Classification	Analysis Conditions			Remark
Applied standard	KS F 4934 (Self Adhesive Rubberized Asphalt Sheet)			-
Waterproofing material composition	Self adhesive rubberized asphalt + sheet (high density polypropylene film or synthetic polymer sheet) accumulation			-
No. of data products	Total of 34 products (P- No. 1~34)			2018–2019 test
Test value collection criteria (9 criteria)	Test and evaluation criteria		No. of test pieces	Table 4's 9 quantitative performance criteria
	(a) Tensile performance	(1) Tensile strength (N/mm)	5	
		(2) Elongation ratio (%)	5	
	(b) Tearing performance		5	
	(c) Temperature dependency performance	(1) 60 °C tensile strength (N/mm)	5	
		(2) 60 °C elongation ratio (%)	5	
		(3) −20 °C tensile strength (N/mm)	5	
		(4) −20 °C elongation ratio (%)	5	
	(d) Adhesion part stability performance (N/mm)		5	
	(e) Adhesion performance (N/mm)		5	
Data selection condition	Use only test values that passed KS F 4934 performance standard			-
Test institution	Seoul National University of Science and Technology Construction Technology Research Institute Waterproofing Technology Research Center			(National quality test institution)

Table 4. Performance and test method required for each of KS F 4934 performance evaluation criteria.

Performance Criteria		Definition	Test Method
Tensile performance	Tensile strength	Maximum stress without destruction under tensile load in structure and joint, etc.	Install test piece in tensile strength tester (UTM) with distance between the bindings as 60 mm, and pull until with 200 mm/min tensile speed until test piece is broken, calculate tensile strength and elongation ratio according to the calculation method specified in the specification and record.
	Elongation ratio	Maximum ratio of being stretched	
Tearing performance		Resistance to endure without tearing under tearing load	Use the same tensile strength tester (UTM) and test method as the same as the above tensile performance, calculate tearing strength according to the specified calculation method and record.
Temperature dependency performance	60 °C	Resistance that can endure at 60 °C temperature (tensile strength, elongation ratio)	Leave alone test piece at (60 ± 2) °C and (−20 ± 2) °C test temperature for 1 h or more and apply the same tensile strength tester UTM) and test method as the above tensile performance to pull until the test piece is broken, calculate tensile strength and elongation ratio for each temperature according to the calculation method specified in the specification and record.
	−20 °C	Resistance that can endure at −20 °C low temperature (tensile strength, elongation ratio)	
Peeling resistance performance of adhesion part stability performance		Stability performance of adhesion part between sheets during waterproofing construction	Attach test piece cut to width 50 mm and length 110 mm to self adhesive surface and protective layer—polyethylene film and sheet—or protective film surface, mount the both end parts 10 mm that are not attached to tensile strength tester with binding interval 100 mm, measure pulling weight with 200 mm/min tensile strength, calculate according to the calculation method specified in the specification and record.
Adhesion performance (peel-out)		Adhesion performance between waterproofing material and base concrete	Spray primer designated by manufacturer on 210 mm × 70 mm text reinforced cement plate, and in standard state, dry according to the specification of manufacturer, process width 50 mm and length 150 mm waterproofing sheet with length direction 60 mm release paper to attach on bottom test plate, fix one end that is not attached to tensile strength tester (UTM) with peeling angle of (90 ± 5)°, first peel 20 mm, then peel the sheet with 100 mm/min tensile speed to calculate peeling load value specified in the specification according to the calculation method and record.

The proposed grading system has been applied to the existing 34 types (products) in Korea, evaluated by Korea's national and public quality test institution, Seoul National University of Science and Technology Construction Technology Research Institute throughout the period of 2 years from 2018 to 2019. These products were selected on the basis that they pass the basic performance requirements outlined in the KS F 4934 standard. For the data range, 5 specimens for each of the testing and evaluation criteria (34 (products) × 9 (test and evaluation criteria) × 5 (No. of test pieces)) resulting in a total of 1530 performance result values were used to demonstrate the proposed grading system application on to the Korean products. Since it is difficult to state such a large number of data values in the article, values of 5 test pieces were averaged and presented for each criteria. As the following results and demonstration is intended to serve only as a proposal for a tool to overcome the limit of indiscriminately unified minimum quality performance standard used as standard in most countries including Korea, products discussed in this study will be limited to those in Korea, but necessity of standard gradation and the proceeding can be applied to any countries that require such similar grading system in consideration of their respective circumstances.

Also, performance definition and test method [9] required for test value collection criteria of Table 3 are as shown in Table 4.

4.3. Test Result Values for Each Performance Criteria

Test result values [25] of the measurements of 9 performances for each product with 34 products as the target are as in Table 5.

4.4. Test Result Values Grade Section Setting

To classify test result values of each performance criteria of Tables 4 and 5 grades, application ratio of test result value for each grade are set as in the following Table 6. The proposed grading system is a proposal based on the opinions of the experts in Korea, where at least 5 grades are required to classify the quality index of the waterproofing membranes in Korea based on the Grade 5 Scale theory and energy consumption efficiency grade theory applied. (The ranges and grading section, if applied to other nations, is subject to change).

Grade sections are divided with the range of grade 1 with 10% (3 products), grade 2 with 20% (7 products), grade 3 with 40% (13 products), grade 4 with 20% (7 products) and grade 5 with 10% (4 products) for total of 34 test result values. It was calculated with the weight added average of the corresponding ratio's boundary part data value.

To explain this with tensile performance (tensile strength) as a sample, test result values of the products in Table 5 are divided to rank 1 to 34, and the boundary corresponding to grade 1 with 10% is data value of the sample at 3.4, so this data value has 40% weaker performance than the 3rd tensile strength of 14.8 N/mm and 60% bigger strength than the 4th tensile strength of 13.4 N/mm. Data value derived as such is rounded off at the second decimal point to calculate the data value at the boundary of grade 1 and 2 of tensile strength among the final tensile performances, which was 14.2 N/mm. The calculation method is as in Formula (1).

$$13.4\ \text{N/mm} + \{(14.8\ \text{N/mm} - 13.4\ \text{N/mm}) \times (4 - 3.4)\} = 14.24\ \text{N/mm} \quad (1)$$

Accumulated grade ratio is applied with the above weight added average calculation method to calculate 30% of grade 2, which is 10.2 sample data value, 70% of grade 3 which is 23.8 sample data value and 90% of grade 4, which is 30.6 sample data value, as boundary standard value of each grade. Grades and the set sections of 9 performance criteria reflecting these are as follows.

Table 5. Test values for each performance criteria.

Classification	Tensile Performance		Tearing Performance	Temperature Dependency				Adhesion Part Stability Performance (N/mm)	Adhesion Performance (N/mm)
				60 °C		−20 °C			
	Tensile Strength (N/mm)	Elongation Ratio (%)		Tensile Strength (N/mm)	Elongation Ratio (%)	Tensile Strength (N/mm)	Elongation Ratio (%)		
P- 01	13.4	377.0	55.0	4.5	216.0	23.2	81.0	2.5	2.0
P- 02	14.8	392.0	60.0	4.4	222.0	23.5	91.0	2.1	1.8
P- 03	10.2	1417.0	87.0	9.4	1045.0	9.9	166.0	2.1	1.8
P- 04	5.3	637.0	31.0	3.3	328.0	7.3	185.0	1.8	1.8
P- 05	5.1	674.0	35.0	3.3	206.0	7.9	79.0	1.8	2.0
P- 06	5.4	628.0	32.0	3.2	302.0	7.7	191.0	1.8	1.9
P- 07	5.5	618.0	35.0	4.1	423.0	10.3	235.0	1.9	2.0
P- 08	7.1	624.0	50.0	5.3	426.0	7.9	328.0	2.3	2.2
P- 09	3.9	640.0	32.0	3.1	447.0	5.2	437.0	2.0	1.7
P- 10	15.5	1092.0	50.0	11.0	270.0	25.0	117.0	2.2	4.8
P- 11	6.0	919.0	31.0	3.3	415.0	6.2	289.0	1.7	1.8
P- 12	13.1	417.0	42.0	10.4	292.0	18.3	234.0	2.3	2.3
P- 13	11.8	480.0	36.0	9.7	215.0	16.0	170.0	2.1	1.8
P- 14	9.1	597.0	35.0	10.4	204.0	16.7	199.0	2.4	1.9
P- 15	10.0	465.0	36.0	9.6	200.0	15.2	180.0	2.2	1.7
P- 16	27.9	1134.0	137.0	23.3	860.0	33.6	219.0	2.5	2.4
P- 17	8.1	737.0	50.0	7.7	563.0	12.0	358.0	2.5	3.8
P- 18	7.5	1257.0	45.0	5.0	289.0	7.5	388.0	2.5	3.2
P- 19	6.9	1277.0	45.0	3.8	450.0	12.0	347.0	3.6	3.3
P- 20	8.6	951.0	40.0	6.5	566.0	12.0	399.0	4.1	3.8
P- 21	5.5	753.0	30.0	3.4	194.0	7.7	320.0	2.1	2.4
P- 22	5.5	806.0	42.0	4.3	245.0	6.0	283.0	2.4	2.4
P- 23	4.9	626.0	37.0	4.2	305.0	7.8	331.0	2.2	3.6
P- 24	4.9	725.0	31.0	3.4	422.0	6.8	213.0	1.8	1.9

Table 5. *Cont.*

Classification	Tensile Performance		Tearing Performance	Temperature Dependency				Adhesion Part Stability Performance (N/mm)	Adhesion Performance (N/mm)
				60 °C		−20 °C			
	Tensile Strength (N/mm)	Elongation Ratio (%)		Tensile Strength (N/mm)	Elongation Ratio (%)	Tensile Strength (N/mm)	Elongation Ratio (%)		
P- 25	12.8	634.0	35.0	4.6	313.0	14.8	84.0	1.7	2.0
P- 26	9.2	913.0	97.0	6.8	351.0	16.7	214.0	1.9	2.1
P- 27	8.6	925.0	99.0	6.7	317.0	16.1	336.0	1.6	2.1
P- 28	9.6	521.0	37.0	11.2	226.0	17.3	134.0	2.6	2.1
P- 29	7.5	817.0	41.0	5.8	453.0	12.5	248.0	2.6	3.0
P- 30	4.5	413.0	39.0	4.1	225.0	7.8	150.0	2.0	2.8
P- 31	5.6	519.0	49.0	4.5	344.0	10.4	239.0	4.6	4.8
P- 32	4.4	477.0	38.0	3.3	263.0	7.7	96.0	1.9	2.1
P- 33	4.0	491.0	39.0	4.2	211.0	10.1	169.0	2.2	2.1
P- 34	6.8	502.0	61.0	5.5	619.0	8.7	206.0	2.1	2.0

(Explanatory Note: "P" Product).

Table 6. Proposed 5 Grade 5 Scale system.

Classification	Grade Section Application Ratio	Grounds for Application
Grade 1	10%	2.2 Grade 5 Scale theory and energy consumption efficiency grade theory applied
2	20%	
3	40%	
4	20%	
5	10%	

4.4.1. Tensile Performance Grade

(1) Tensile strength

To set grade section for tensile strength test data by Table 7, they were derived as grade 1 with 14.2 N/mm or more, grade 2 with 9.5 N/mm or more and less than 14.2 N/mm, grade 3 with 5.5 N/mm or more and less than 9.5 N/mm, grade 5 with 4.7 N/mm or more and less than 5.5 N/mm and grade 5 with 3.0 N/mm or more and less than 4.7 N/mm. To show these as graph, they were set as in the following Figure 1.

(2) Elongation ratio

According to Table 7, setting sections of each grade of standard test data value of elongation ratio were derived as in the following Figure 2, which were grade 1 with 1208% or more, grade 2 with 815% or more and less than 1208%, grade 3 with 536% or more and less than 815%, grade 4 with 436% or more and less than 536% and grade 5 2 with 200% or more and less than 436%.

Table 7. Grade section setting of each of 9 test criteria of KS F 4934.

Classification			Standard Value Section for Each Grade					KS Performance Standard *
			Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	
Tensile performance	Tensile strength (N/mm)		14.2 ≤ S	9.5 ≤ S < 14.2	5.5 ≤ S < 9.5	4.7 ≤ S < 5.5	3.0 ≤ S < 4.7	3.0 or more
	Elongation ratio (%)		120 ≤ E	815 ≤ E < 1208	536 ≤ E < 815	436 ≤ E < 536	200 ≤ E < 436	200 or more
Tearing performance (N)			93.0 ≤ S	49.8 ≤ S < 93.0	36.0 ≤ S < 49.8	31.4 ≤ S < 36.0	25.0 ≤ S < 31.4	25 or more
Temperature dependency	Test temperature 60 °C	Tensile strength (N/mm)	10.8 ≤ S	6.8 ≤ S < 10.8	4.1 ≤ S < 6.8	3.3 ≤ S < 4.1	2.0 ≤ S < 3.3	2.0 or more
		Elongation ratio (%)	598 ≤ E	423 ≤ E < 598	249 ≤ E < 423	208 ≤ E < 249	150 ≤ E < 208	150 or more
	Test temperature −20 °C	Tensile strength (N/mm)	23.4 ≤ S	15.8 ≤ S < 23.4	7.8 ≤ S < 15.8	7.0 ≤ S < 7.8	5.0 ≤ S < 7.0	5.0 or more
		Elongation ratio (%)	376 ≤ E	287 ≤ E < 376	172 ≤ E < 287	93 ≤ E < 172	50 ≤ E < 93	50 or more
Adhesion part stability performance (N/mm)			3.2 ≤ S	2.4 ≤ S < 3.2	2.0 ≤ S < 2.4	1.8 ≤ S < 2.0	1.5 ≤ S < 1.8	1.5 or more
Adhesion performance (N/mm)			3.8 ≤ S	2.4 ≤ S < 3.8	2.0 ≤ S < 2.4	1.8 ≤ S < 2.0	1.5 ≤ S < 1.8	1.5 or more

* Performance standard of Table 4 (basic quality standard).

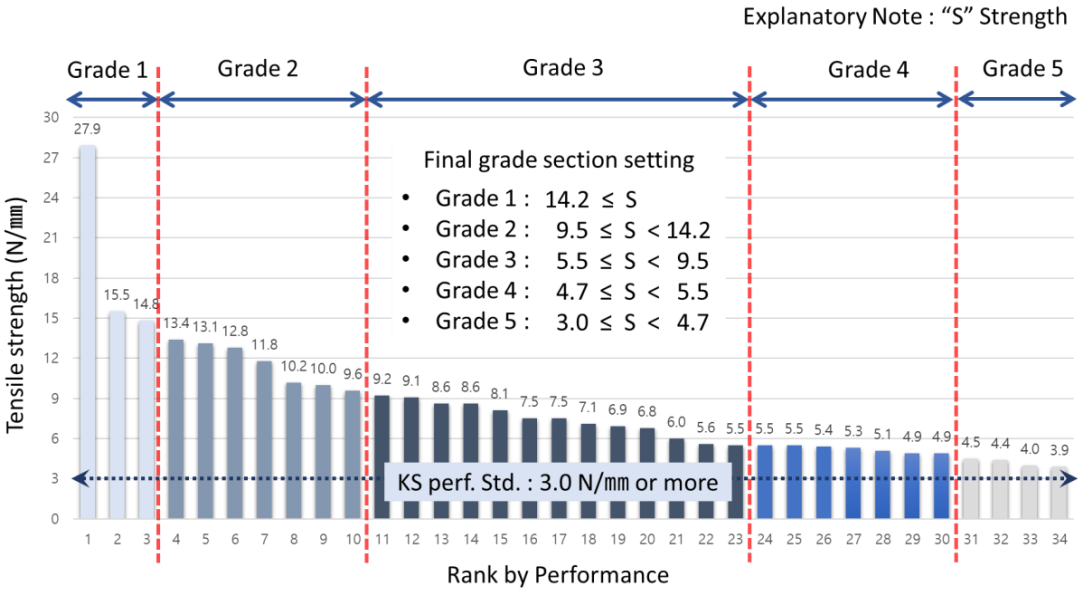


Figure 1. Section setting for each grade of tensile strength.

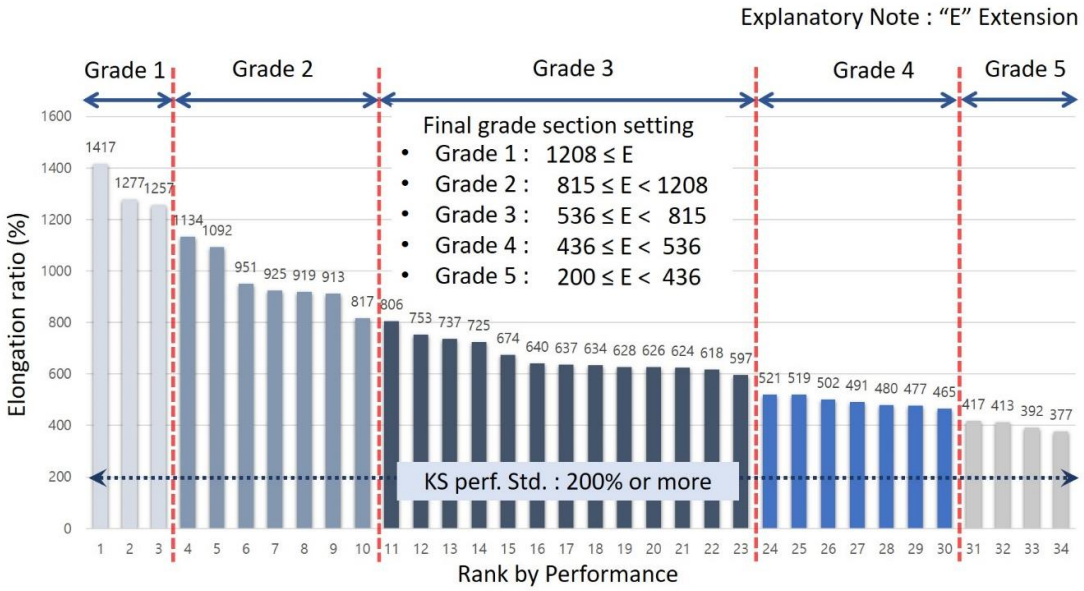


Figure 2. Section setting for each grade of elongation ratio.

4.4.2. Tearing Performance Grade

According to Table 7, tearing performances were derived as grade 1 with 93.0 N or more, grade 2 with 49.8 N or more and less than 93.0 N, grade 3 with 36.0 N or more and less than 49.8 N, grade 4 with 31.4 N or more and less than 36.0 N and grade 5 with 25 N or more and less than 31.4 N. To show these in graph, they were set as in the following Figure 3.

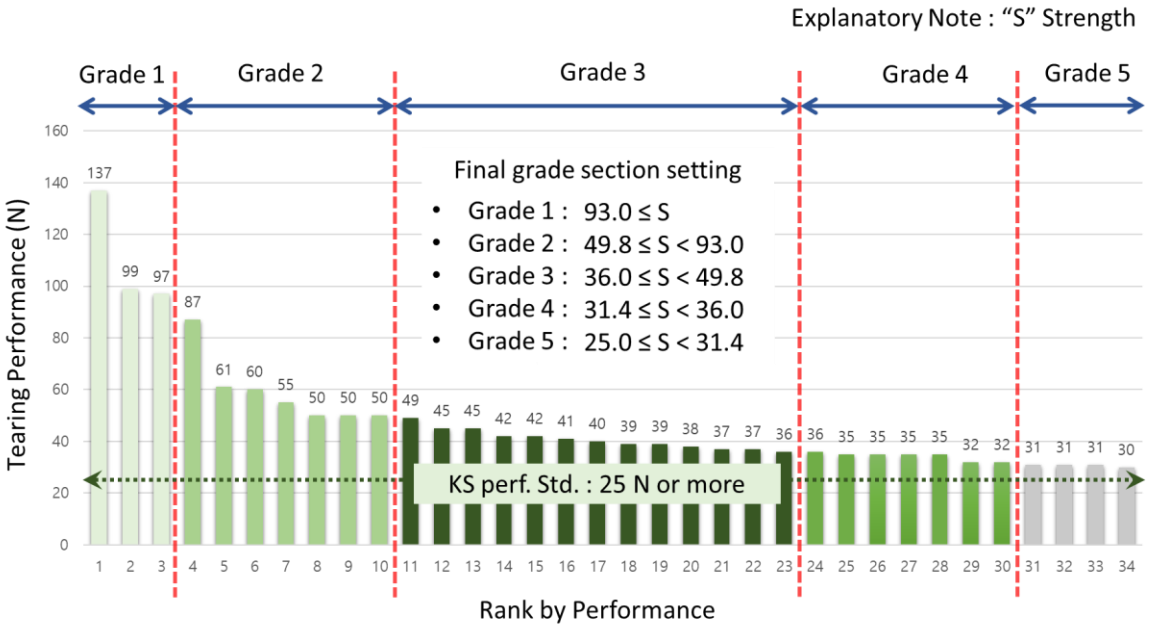


Figure 3. Section setting for each grade of tearing performance.

4.4.3. Temperature Dependency Performance Grade

(1) Room temperature 60 °C tensile strength

According to Table 7, room temperature 60 °C tensile strength section setting of each grade of standard test data values is as in the following Figure 4. When you look at the set grade sections, they were derived as grade 1 with 10.8 N/mm or more, grade 2 with 6.8 N/mm or more and less than 10.8 N/mm, grade 3 with 4.1 N/mm or more and less than 6.8N/mm, grade 4 with 3.3 N/mm or more and less than 4.1 N/mm and grade 5 with 2.0 N/mm or more and less than 3.3 N/mm.

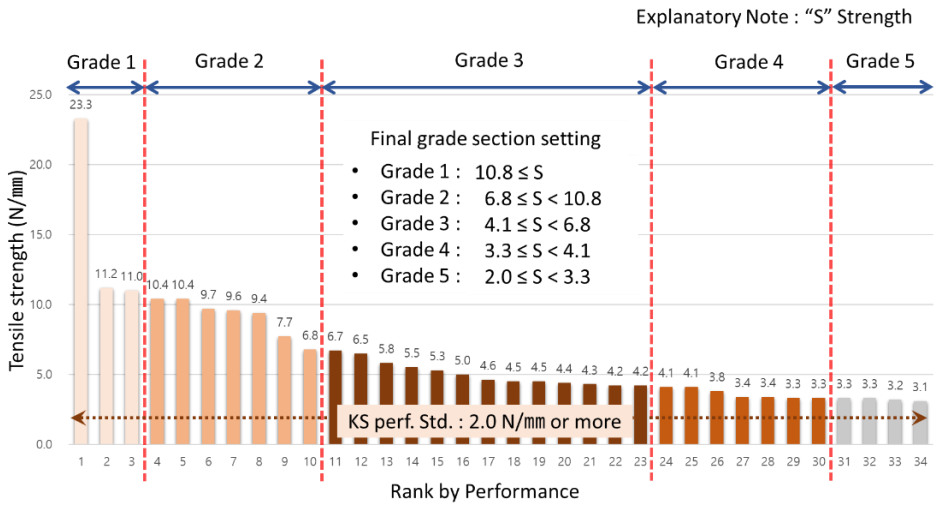


Figure 4. Section setting for each grade of room temperature 60 °C tensile strength.

(2) 60 °C elongation ratio

According to Table 7, to set grade section for elongation ratio between binding parts in case of fracture at room temperature 60 °C, they were derived as grade 1 with 598% or more, grade 2 with 423% or more and less than 598%, grade 3 with 429% or more and less than 249%, grade 4 with 208% or more and less than 429% and grade 5 with 150% or more and less than 208%. To show these in graph, they were set as in the following Figure 5.

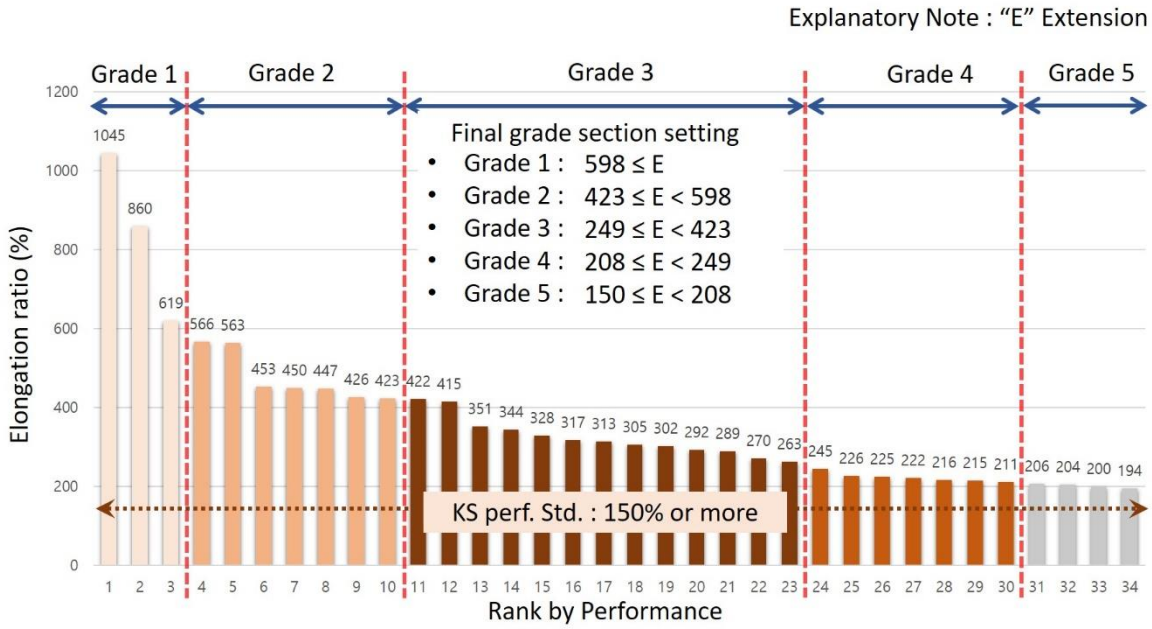


Figure 5. Section setting for each grade of room temperature 60 °C elongation ratio.

(3). −20 °C tensile strength

According to Table 7, to set grade section for standard test data value of low temperature −20 °C tensile strength, they were derived as grade 1 with 23.4 N/mm or more, grade 2 with 15.8 N/mm or more and less than 23.4 N/mm, grade 3 with 7.8 N/mm or more and less than 15.8 N/mm, grade 4 with 7.0 N/mm or more and less than 7.8 N/mm and grade 5 with 5.0 N/mm or more and less than 7.0 N/mm. To show these in graph, they were set as in the following Figure 6.

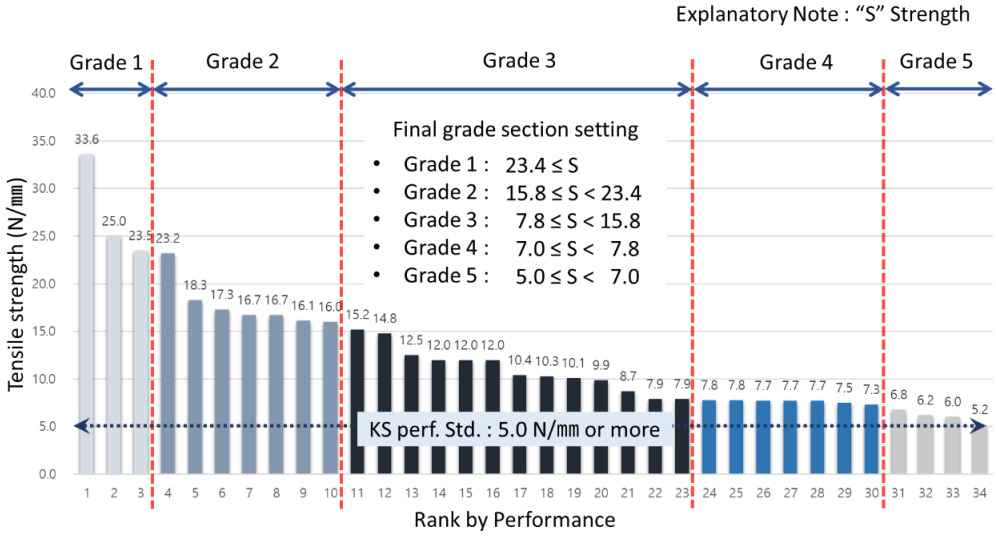


Figure 6. Section setting for each grade of low temperature −20 °C tensile strength.

(4) −20 °C elongation ratio

According to Table 7, to set grade section for standard test data value for elongation ratio between binding parts in case of fracture at low temperature −20 °C, they are as in the following Figure 7. Set sections were derived as grade 1 with 376% or more, grade 2 with 287% or more and less than 376%, grade 3 with 172% or more and less than 287%, grade 4 with 93% or more and less than 172% and grade 5 with 50% or more and less than 93%.

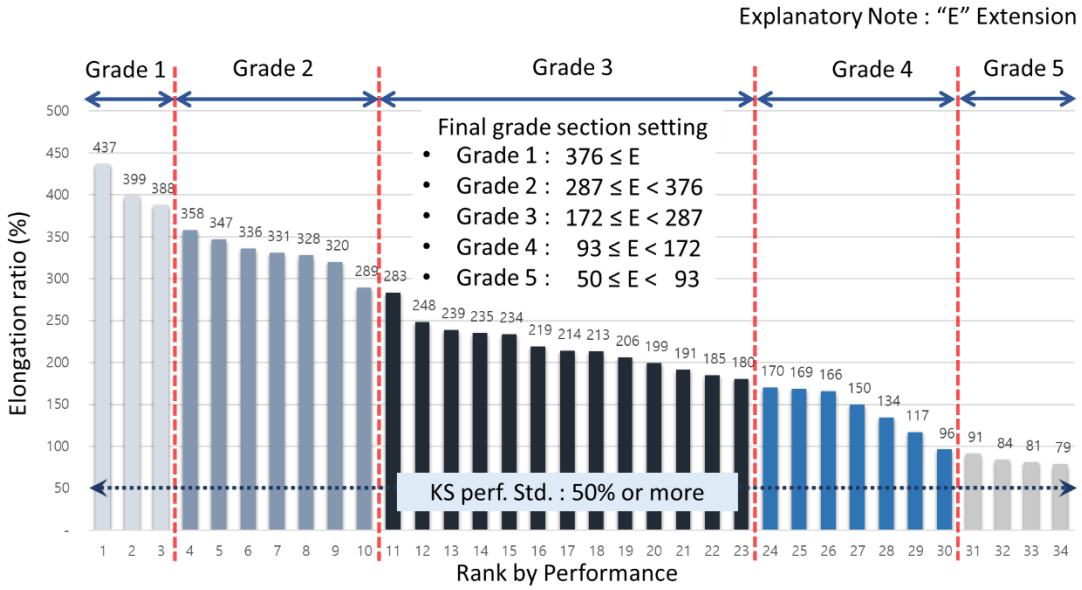


Figure 7. Section setting for each grade of low temperature −20 °C elongation ratio.

4.4.4. Adhesion Part Stability Performance Grade

According to Table 7, to set grade section for adhesion part stability performance test data value, as in the following Figure 8, they were derived as grade 1 with 3.2 N/mm or more, grade 2 with 2.4 N/mm or more and less than 3.2 N/mm, grade 3 with 2.0 N/mm or more and less than 2.4 N/mm, grade 4 with 1.8 N/mm or more and less than 2.0 N/mm and grade 5 with 1.5 N/mm or more and less than 1.8 N/mm.

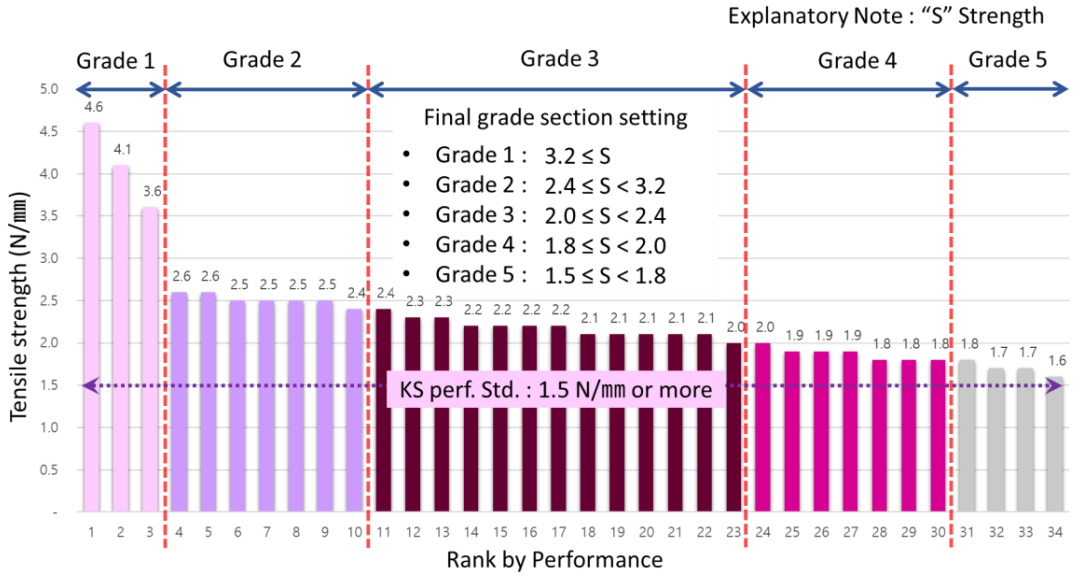


Figure 8. Section setting for grade of adhesion part stability performance.

4.4.5. Adhesion Performance Grade

According to Table 7, to set section of each grade of adhesion performance test data values, it is as in the following Figure 9. When you look at the set sections, they were derived as grade 1 with 3.8 N/mm or more, grade 2 with 2.4 N/mm or more and less than 3.8 N/mm, grade 3 with 2.0 N/mm or more and less than 2.4 N/mm, grade 4 with 1.8 N/mm or more and less than 2.0 N/mm and grade 5 with 1.5 N/mm or more and less than 1.8 N/mm.

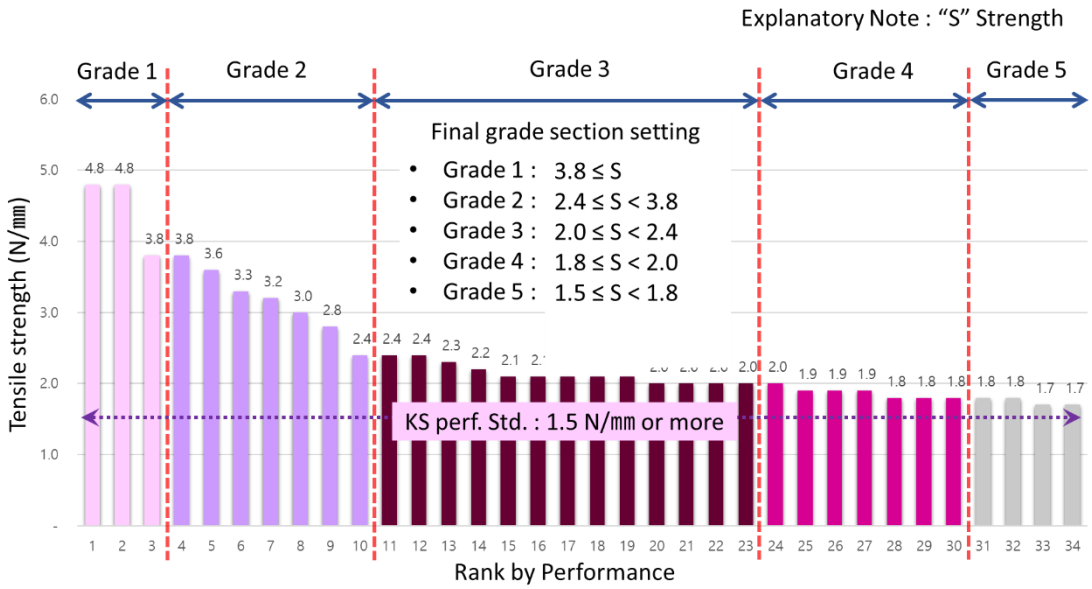


Figure 9. Section setting for grade of adhesion performance.

4.5. Grade Section of Quality Standard for Each Performance Criteria

For 9 performance criteria of self adhesive type rubberized asphalt waterproofing sheet (KS F 4934) 34 products, performance sections for each of 5 grades are comprehensively listed as in Table 7.

4.6. Waterproofing Performance Gradation

To derive performance grade for each evaluation criteria of 34 products (samples) based on the setting result of the grade section of each of 9 test criteria of the above Table 7, it is as in Table 8. In case of sample (product) P- 01, it was derived as product corresponding to waterproofing performance grade of tensile strength grade 2, elongation ratio grade 5, tearing performance grade 2, room temperature 60 °C tensile strength of temperature dependency grade 3, elongation ratio grade 4, low temperature –20 °C tensile strength grade 2, elongation ratio grade 5, peeling resistance performance of adhesion stability performance grade 2 and adhesion performance grade 3.

Table 8. Grade of each performance criteria of 34 products (samples) of KS F 4934.

Classification	Derivation of Grade for Each Performance Criteria								
	Tensile Performance		Tearing Performance	Temperature Dependency				Adhesion Part Stability Performance (N/mm)	Adhesion Performance (N/mm)
				Test Temperature 60 °C		Test Temperature −20 °C			
	Tensile Strength (N/mm)	Elongation Ratio (%)		Tensile Strength (N/mm)	Elongation Ratio (%)	Tensile Strength (N/mm)	Elongation Ratio (%)		
P- 01	2	5	2	3	4	2	5	2	3
P- 02	1	5	2	3	4	1	5	3	4
P- 03	2	1	2	2	1	3	4	3	4
P- 04	4	3	5	4	3	4	3	4	4
P- 05	4	3	4	5	5	3	5	4	3
P- 06	4	3	4	5	3	4	3	4	4
P- 07	3	3	4	4	2	3	3	4	3
P- 08	3	3	2	3	2	3	2	3	3
P- 09	5	3	4	5	2	5	1	3	5
P- 10	1	2	2	1	3	1	4	3	1
P- 11	3	2	5	5	3	5	2	5	5
P- 12	2	5	3	2	3	2	3	3	3
P- 13	2	4	3	2	4	2	4	3	5
P- 14	3	3	4	2	5	2	3	2	4
P- 15	2	4	4	2	5	3	3	3	5
P- 16	1	2	1	1	1	1	3	2	2
P- 17	3	3	2	2	2	3	2	2	1
P- 18	3	1	3	3	3	4	1	2	2
P- 19	3	1	3	4	2	3	2	1	2
P- 20	3	2	3	3	2	3	1	1	2
P- 21	4	3	5	4	5	4	2	3	3
P- 22	4	3	3	3	4	5	3	3	3
P- 23	4	3	3	3	3	4	2	3	2
P- 24	4	3	5	4	3	5	3	5	4
P- 25	2	3	4	3	3	3	5	5	3

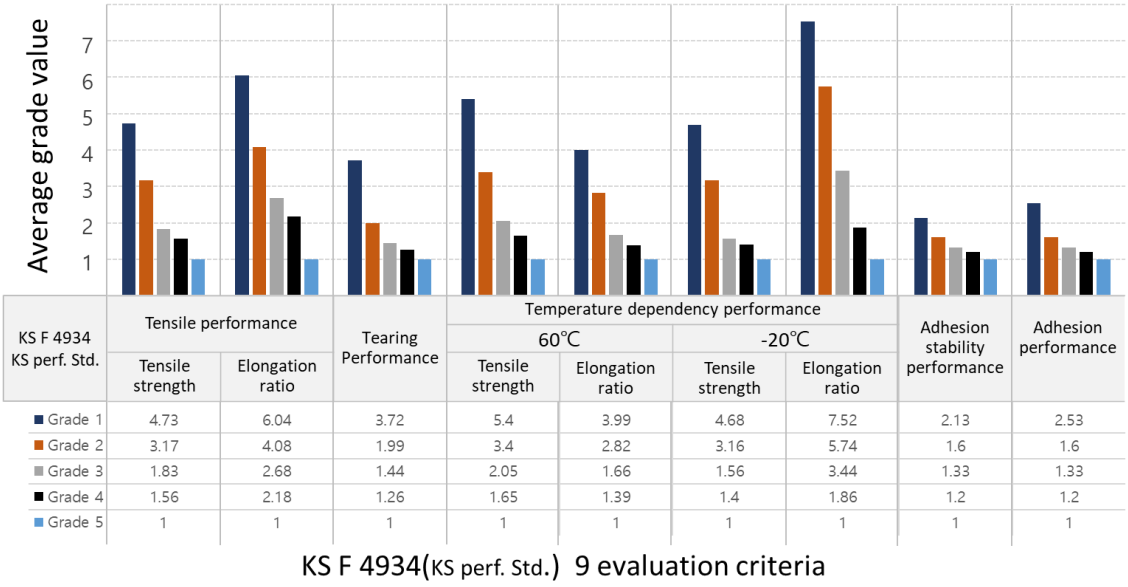
Table 8. *Cont.*

Classification	Derivation of Grade for Each Performance Criteria								
	Tensile Performance		Tearing Performance	Temperature Dependency				Adhesion Part Stability Performance (N/mm)	Adhesion Performance (N/mm)
				Test Temperature 60 °C		Test Temperature −20 °C			
	Tensile Strength (N/mm)	Elongation Ratio (%)		Tensile Strength (N/mm)	Elongation Ratio (%)	Tensile Strength (N/mm)	Elongation Ratio (%)		
P- 26	3	2	1	2	3	2	3	4	3
P- 27	3	2	1	3	3	2	2	5	3
P- 28	2	4	3	1	4	2	4	2	3
P- 29	3	2	3	3	2	3	3	2	2
P- 30	5	5	3	4	4	4	4	4	2
P- 31	3	4	3	3	3	3	3	1	1
P- 32	5	4	3	4	3	4	4	4	3
P- 33	5	4	3	3	4	3	4	3	3
P- 34	3	4	2	3	1	3	3	3	4

Note: "P" Product.

4.7. Effectiveness Analysis of Waterproofing Performance Gradation

The purpose of this study was to find the solution for the limit by the application of unified quantitative single performance quality standard [26] applied currently as standard in each country and thus becoming hindering element against waterproofing performance quality reinforcement with new concept quality management method through waterproofing performance gradation. To review whether the contents studied under such purpose can actually bring the desired effect, deviation of the performance in each grade section of Figure 10 derived as a result was analyzed.



KS F 4934 KS perf. Std.	Tensile performance		Tearing Performance	Temperature dependency performance				Adhesion stability performance	Adhesion performance
				60℃		-20℃			
	Tensile strength	Elongation ratio		Tensile strength	Elongation ratio	Tensile strength	Elongation ratio		
Grade 1	4.73	6.04	3.72	5.4	3.99	4.68	7.52	2.13	2.53
Grade 2	3.17	4.08	1.99	3.4	2.82	3.16	5.74	1.6	1.6
Grade 3	1.83	2.68	1.44	2.05	1.66	1.56	3.44	1.33	1.33
Grade 4	1.56	2.18	1.26	1.65	1.39	1.4	1.86	1.2	1.2
Grade 5	1	1	1	1	1	1	1	1	1

Figure 10. Performance deviation of each test evaluation criteria.

In Figure 10, to contemplate tensile strength as a case, with 1.00(3.0 N/mm) of grade 5 as basic quality (minimum quality) standard, when you loot at deviation of each performance, grade 4 was 1.56 times (5.5 N/mm), grade 3 was 1.83 times (9.2 N/mm), grade 2 was 3.17 times (13.4 N/mm) and grade 1 was 4.73 times (27.9 N/mm), which shows that somewhat big performance deviation product is currently used in actual waterproofing construction site. That is, it means that, in 9 performance evaluation criteria of KS F 4934 (Self Adhesive Rubberized Asphalt Sheet) standard specification, waterproofing material of high deviation of minimum 1.2 times up to maximum of 7.52 times is applied to the site.

In other words, under all the same conditions at waterproofing construction site (construction, environment, economic feasibility, maintenance, etc.), it was verified that waterproofing material with high deviation from minimum of 1.2 times up to maximum of 7.52 times is used along with the basic performance material at the same time.

With such result, limit of the existing unified single performance application can be sufficiently recognized, and as a solution for waterproofing quality degradation problem, it is decided as necessary to apply the waterproofing performance gradation of this study.

5. Conclusions

This study researched and reviewed new concept waterproofing performance gradation as overall performance standard quality management method getting out of the unified quantitative single "minimum quality standard management method" specified as standard in most countries.

This study was carried out using the performance evaluation result values of 34 products (waterproofing material) and 9 waterproofing performance criteria tested and evaluated by Korea's national quality test institution for 2 years (2018~2019) based on standard specification (KS F 4934,

Self Adhesive Rubberized Asphalt Sheet). Also, standard grading systems (Stanine, Sten Scores, Grade 5 Scale, energy consumption efficiency and other grades) used in various areas were surveyed and analyzed. As a result, Grade 5 Scale standard system that can correspond to waterproofing performance was selected by collecting the opinions of the experts. Grade 5 Scale standard grade classification ratio (grade 1 with 10%, grade 2 with 20%, grade 3 with 40%, grade 4 with 20% and grade 5 with 10%) was applied to set the grade sections. Using the set sections, waterproofing performance grades of 9 test criteria for each of 34 products were derived.

Thus, through this proposal, the possibility was verified to apply new concept standard gradation to overcome the limit as a tool to maintain minimum quality for unified single performance standard applied in accordance to the respective national circumstances. Also, effectiveness of standard gradation application was reviewed through analysis of performance deviation in each grade section. As a result, it was verified that somewhat high deviation waterproofing material from minimum of 1.2 times up to maximum of 7.52 times is used along with basic performance material at the same time. This shows the necessity of quality gradation since waterproofing material with big performance deviation is used at the waterproofing construction site under all the same conditions (construction, environment, economic feasibility, maintenance, etc.). Such result verifies that, through waterproofing performance gradation, limit of the current quality standard application can be solved and reinforcement of product selection standard for waterproofing quality improvement is possible. However, the results of the study, at this stage in time, is only a point of consideration that requires further validation through testing with a heavier database, and the proposed grading system will require further revision before it can be considered as a standardized format. Therefore, through this study, new concept quality standard that can pursue future waterproofing industry development can be set and sustainable waterproofing performance maintaining effect at the waterproofing construction site can be expected with the use of such gradation.

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Abbreviations

KS	Korea Industrial Standards
JIS	Japan Industrial Standard
ANSI	American National Standards Institute
ASTM	American Society for Testing Materials
GB	Guojia Biaozhun
BS	British Stnadard
DIN	Deutsches Institut fur Normung
NFPA	National Fire Protection Association
UTM	Universal Testing Machine

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