ASSESSMENT OF SINGLE-PLY ROOFING IN JAPAN

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Single-ply roofing has been used as a roofing membrane for 30 years in Japan. Twenty-five million square meters (250 million sq. ft.) of single-ply roofing, including EPDM rubber sheets and PVC sheets, were constructed in 1989. The reliability of the materials and practices have been improved for many years mainly through problems experienced by manufacturers in field applications. In 1986, the Architectural Institute of Japan proposed the testing methods for assessment of single-ply roofing, and our Polymer Roofing Sheet Manufacturers' Association started to evaluate their membranes according to these methods. This paper outlines the test methods and results, and some proposals for improvements.

The tested items are: watertightness; resistance to cyclic movement; venting resistance between membrane and substrate; resistance to blow-off under suction, and other material evaluations.

KEYWORDS

Dimensional stability, dynamic puncture, resistance to blow-off under suction, resistance to cyclic movement, resistance to slippage, single-ply roofing, static puncture, venting resistance between membrane and substrate, watertightness.

INTRODUCTION

In 1983, the European Union of Agrement (UEAtc) published the General Directive for the Assessment of Roofing Waterproofing Systems as the first proposal. The assessment method of membrane roofing systems had been studied for three years based on field and laboratory experiences in Japan, and was released as an appendix of Japanese Architecture Standard Specification in 1986 from the Architectural Institute of Japan.

Polymer Roofing Sheet Manufacturers' Association in Japan started the assessment methods for single-ply membranes in 1987. This includes elastomeric and plastomeric membranes, and modified bitumen membranes such as ethylene-propylene-diene terpolymer (EPDM - vulcanized and unvulcanized rubber), polyvinyl chloride (PVC), ethylene vinyl acetate (EVA) and modified bitumen (SBS) as shown in Table 1.

WATERTIGHTNESS TEST

A single-ply roofing membrane is less than 4mm thick and is necessarily joined on-site by workers. Watertightness of single-ply roofing is very important especially at lap joints, at penetrations and at corners of substratum.

Box Type Test

The substrate construction for the specimen is composed of 12mm thick wooden plates and steel channels as shown in Figure 1, and a sample of single-ply roofing will be applied inside the box according to the normal application method. The temperature of the air inside the box should be 70°C.

- Three days after the application at room temperature for vulcanized rubber roofing (seven days for non-vulcanized rubber roofing and modified bitumen roofing dependent on stabilizing time), water will be poured into specimen to a height of 800mm. Leakage will be checked for 14 days from pouring at room temperature.
- After the specimen is heated at 70°C for 28 days, water will be poured into the specimen to a height of 800mm. Leakage will be checked for 14 days from pouring at room temperature.

There was no leakage of the various roofing specimens except for modified bitumen roofing. The watertightness test proved to be effective in evaluating watertightness of the roofings because some leakage was observed in the case of modified bitumen roofing (3.2mm thickness) at rectangular corners around a pipe, and no leakage was observed when the corner was canted. As the roofing is applied inside a narrow box, the application job seems to be inconvenient and somewhat dangerous, especially for torching of modified bitumen roofing.

Watertightness Test at Critical Portions

In order to investigate new materials and application methods for each critical portion such as T-joint, around a pipe or around a projection, watertightness tests at critical portions are convenient and practical. Three types of watertightness tests were designed at critical portions apart from the box type test.

A T-joint was installed on 500mm X 500mm wooden plates and 400mm diameter X 400mm long PVC pipe was attached with sealant at the joint as shown in Figure 2. Then the pipe was filled with water. Two types of box substrate of 800mm x 800mm x 400mm high were prepared for the test around a projection (Figure 3) and around a pipe (Figure 4). Three kinds of roofing, vulcanized rubber, non-vulcanized rubber and PVC sheets, were applied inside the boxes. The roofing was applied by two kinds of methods according to the standard and a careless method, such as T-joint without sealing and butt jointing, in order to determine the relation between watertightness and application methods.

Three days after the application, water was poured into the boxes to a height of 400mm. Leakage was checked for three days. No leakage was observed on all of the specimens applied by the standard, and some leakage within 24 hours on most of the specimens applied by a careless method, as shown in Table 2. The results confirmed that the watertightness tests at critical portions are easy and effective methods to evaluate new materials and application methods.

The authors propose that the watertightness tests at critical portions are carried out at the initial stage of development of the roofing systems and that the box type tests are performed for final assessment of the roofing system.

RESISTANCE TO CYCLIC MOVEMENT

A roofing membrane is stretched at a substrate crack in the fatigue test for evaluation of resistance to cyclic movement. The sizes of specimens are shown in Figure 5, and the substrate is made of a slate plate with a notch at the center to initiate cracking.

The apparatus for the fatigue test, shown in Figure 6, is composed of a chamber of constant temperature with a mechanism which generates a specific movement to the substrate in a horizontal direction. Each stage consists of 2000 movements of the specimens at the rate of one cycle every four minutes. The fatigue test was carried out through six stages as shown in Table 3. Table 4 shows the results of the fatigue test. No change in the roofing samples except non-vulcanized EPDM rubber and modified bitumen roofing was observed.

A non-vulcanized rubber roofing sample adhered to the substrate failed at the fifth stage because of stress concentration at the substrate crack. No change to the non-vulcanized EPDM roofing was observed in any stage, where the roofing was applied with 30mm wide separation tape at the substrate crack for separating the roofing from the substrate.

A modified bitumen roofing sample at the substrate crack became wrinkled at the fifth stage, but no breakdown of the roofing occurred until the final stage.

These results show that a large number of cyclic movements is effective to determine the fatigue strength of a single-ply roofing membrane, and that separation tape should be used at the substrate cracks.

VENTING RESISTANCE BETWEEN MEMBRANE AND SUBSTRATE

Some blistering of roofing membranes is caused by moisture vapor pressure from substrates, and a roofing application with a vapor path is used to prevent blistering.

As shown in Figure 7, the venting resistance test was performed by the apparatus and a specimen composed of a slate plate and a roofing membrane with vapor path such as one or two lines of ventilation tape or nonwoven layer in Table 5. Compressed air pressure with 10mm water, 20mm water and 30mm water was fed into the inlet of the apparatus. The amount of outflow air per minute was measured by a micro-flow meter.

The test was carried out for the eight roofing systems in Table 5. The results in Figure 8 show that air ventilation of No. 1 among ventilation tape methods is larger than that of No. 3 because of the large air path of nonwoven fabric. Though the air path of No. 4 is similar to that of No. 3, air paths are increased by uneven adhesives applied by notched trowels. It should be noted that difficulty in stabilizing the pressure with 10mm water will cause pressure fluctuation, and that further study of the relation between air ventilation and blister prevention will be required.

RESISTANCE TO BLOW-OFF UNDER SUCTION

A single-ply roofing membrane without protection (such as concrete mortar) should not separate from the substrate under the suction caused by strong wind. This test is proposed for the assessment of a roofing membrane's resistance to blow-off under the suction. A specimen, composed of a slate substrate of 10mm thick and 450mm X 450mm membranes samples bonded to the substrate except at the 100mm X 100mm center, was attached onto the apparatus as shown in Figure 9.

After heating the surface of the roofing to 40°C, the specimen was observed under vacuum pressure of −200mm water, −400mm water, −600mm water, −800mm water or −1000mm water for one hour, respectively. Separated areas of the roofing sample were measured and plotted as shown in Figure 10.

As resistance of a roof to suction is basically contradictory to resistance to air ventilation, the criteria of resistance to suction must be clarified. The test conditions, such as air ventilation of substrate, surface coating of substrate and bonding strength to substrate, should be a subject for further study.

MATERIALS EVALUATION

Though the physical properties of roofing membranes have been specified in the standard specification, additional evaluation is requested in order to evaluate roofing membranes under practical application. Four kinds of testing is proposed as shown in Table 6. The roofing membrane specimens and results of resistance to slippage, static and dynamic puncture are summarized in Table 7.

Resistance to Slippage

The upper half of a roofing membrane was bonded to a 300mm X 300mm vertical concrete plate as shown in Figure 11. After 24 hours at 20°C, 60 percent humidity of the specimen was heated at 50°C, 60°C and 70°C in the air oven.

Because of the low softening point of SBS-modified bitumen, No. 7 and No. 8 specimens show 2mm slippage, respectively, at 50°C and 60°C. These specimens slipped down, respectively, at 60°C after 24 hours and 70°C after 72 hours. This indicates that the flashing by mechanical fastening for roofing edges at upstands are necessary to prevent slip down.

Static Puncture Test

A roofing membrane, 300mm X 300mm, was put on a flat concrete plate. Three steel balls (10mm diameter) and steel plate (200mm diameter, 6mm thick, 15 kgs) were put on the roofing membranes as shown in Figure 12.

Static puncture tests for temperature dependent materials show that non-vulcanized rubber, No. 3, and SBS-modified bitumens, No. 7 and No. 8, got penetration at 50°C, 15 kgs.

Because it seems to be difficult to keep the specimen with 30 kgs or 45 kgs weight horizontal in the air oven, the authors propose that a column (e.g., 11mm diameter) be used instead of the steel balls.

Dynamic Puncture Test

A roofing membrane, 300mm X 300mm, was put on a sheet of asphalt roofing felt (1.5 kgs/m^2) on a concrete plate. A steel ball (50mm diameter, 500 g) was dropped onto the membrane at room temperature from 0.5m, 1.0mm and 1.5mm height as shown in Figure 13.

The results (without asphalt roofing felt) show all of the specimens, except ethylene vinyl acetate and single-ply, do not get any penetration. Though specified in the draft of assessment, the asphalt roofing felt should not be used for the test.

Dimensional Stability Test

Six pieces of 50mm X 300mm specimens were made from roofing membranes, respectively, in the longitudinal and latitudinal directions. After the specimens were exposed in the air oven at 60°C for 24 hours and cooled to the room temperature, standard lengths were measured. The specimens were heated five times in the air oven at 60°C for 24 hours ("dry" in Figure 14) and soaked in water at 60°C for 24 hours ("wet" in Figure 14).

The results of dimensional stability tests (Figure 14) show that length differences from initial length before the first exposure in the air oven increased gradually by repeating dry and wet conditions. Length differences from the standard length between materials are similar. The authors propose that the first exposure for measurement of standard length should be removed.

CONCLUSION

The laboratory study has shown that the watertightness test is useful to evaluate membrane roofing systems, but the apparatus seems to be too large. The watertightness test at critical portions is practical and useful at the initial stage of development of roofing systems.

The relationship between assessment of venting resistance and vacuum resistance and field life will require further study. Materials evaluation tests such as resistance to slippage, static and dynamic puncture and dimensional stability, and the fatigue test are useful for assessment of roofing systems.

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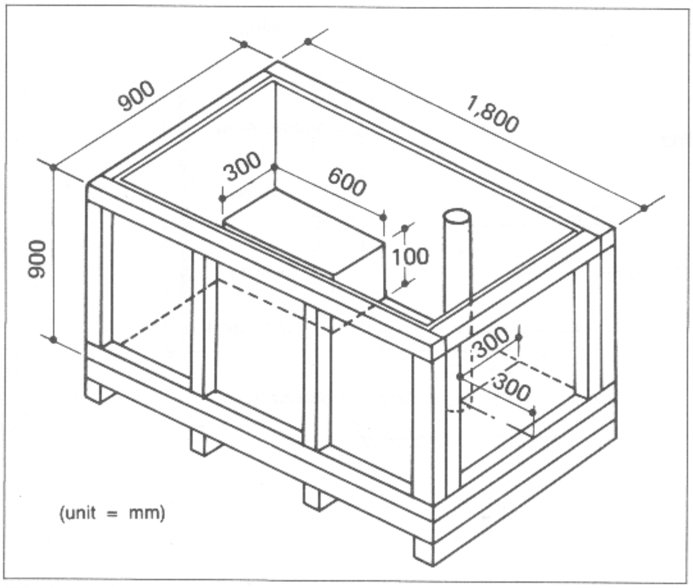

Figure 1 Substratum construction of box type test.

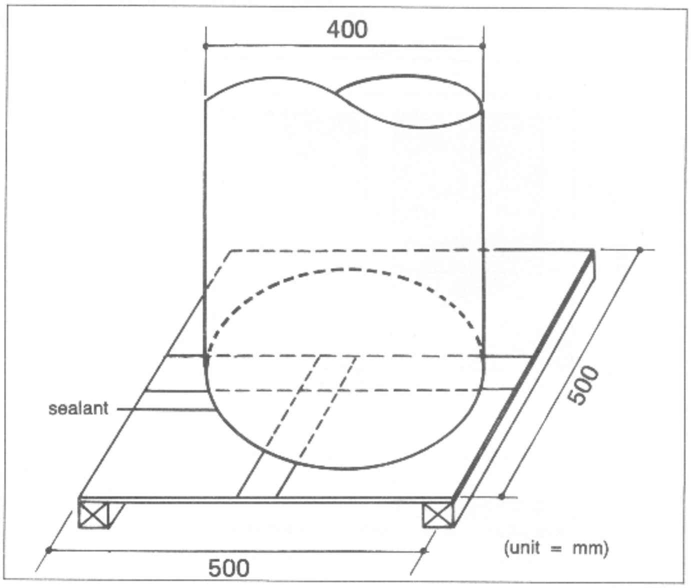

Figure 2 Plate substrate with PVC pipe.

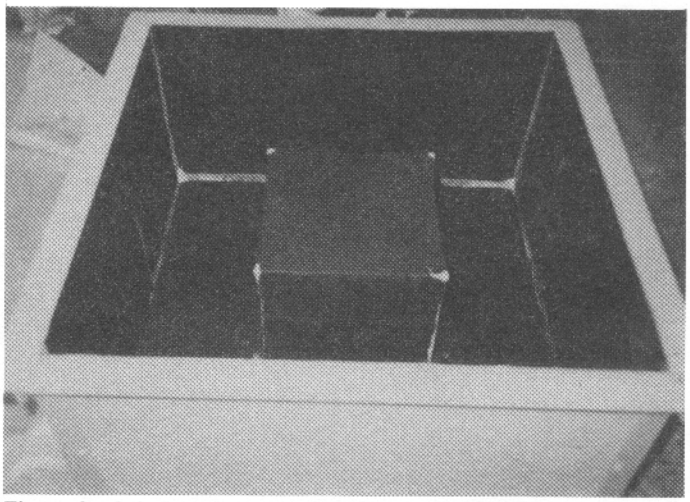

Figure 3 Substrate construction around a projection.

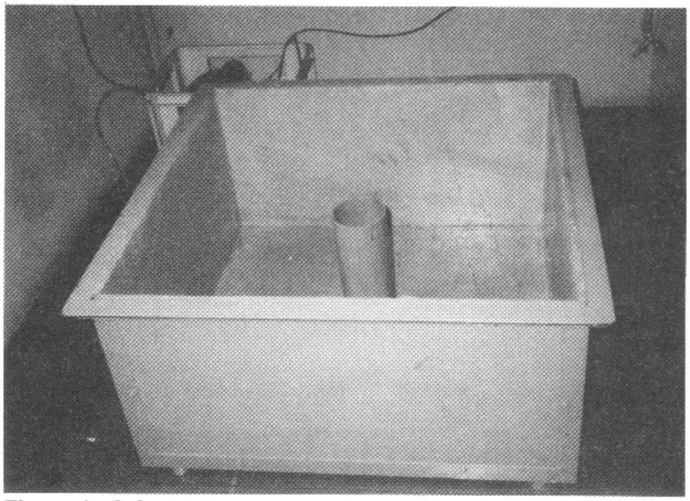

Figure 4 Substrate construction around a pipe.

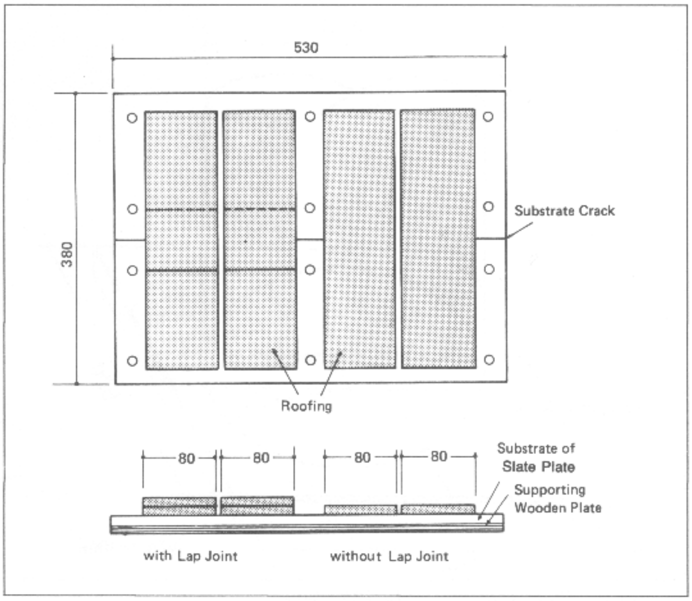

***Figure 5** Specimen for fatigue test.*

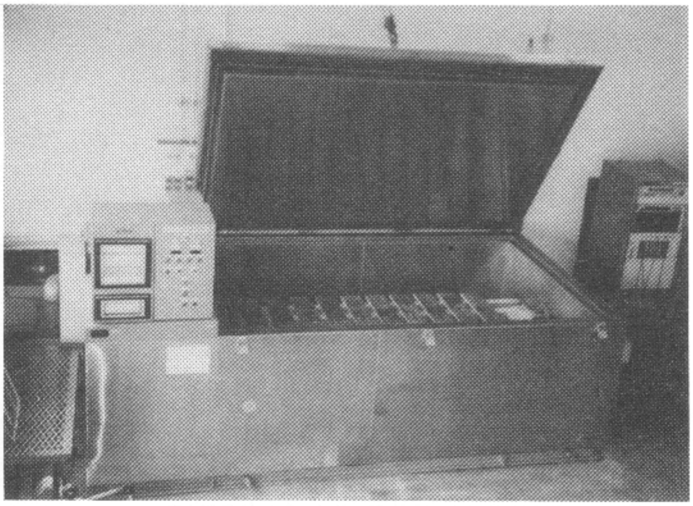

***Figure 6** Apparatus for fatigue test.*

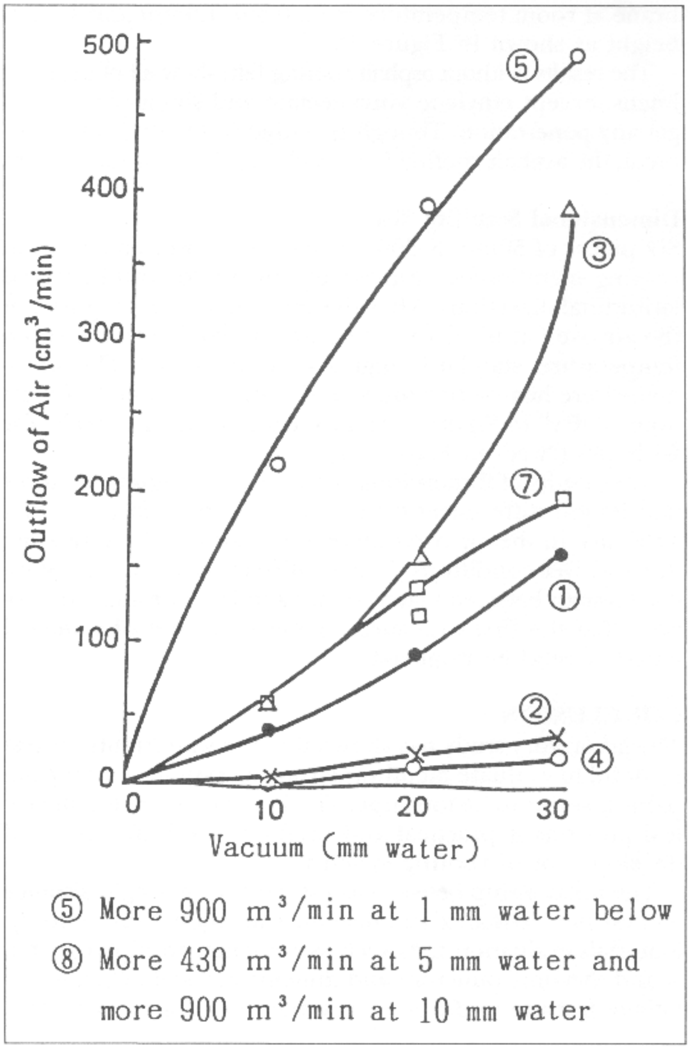

***Figure 8** Venting resistance.*

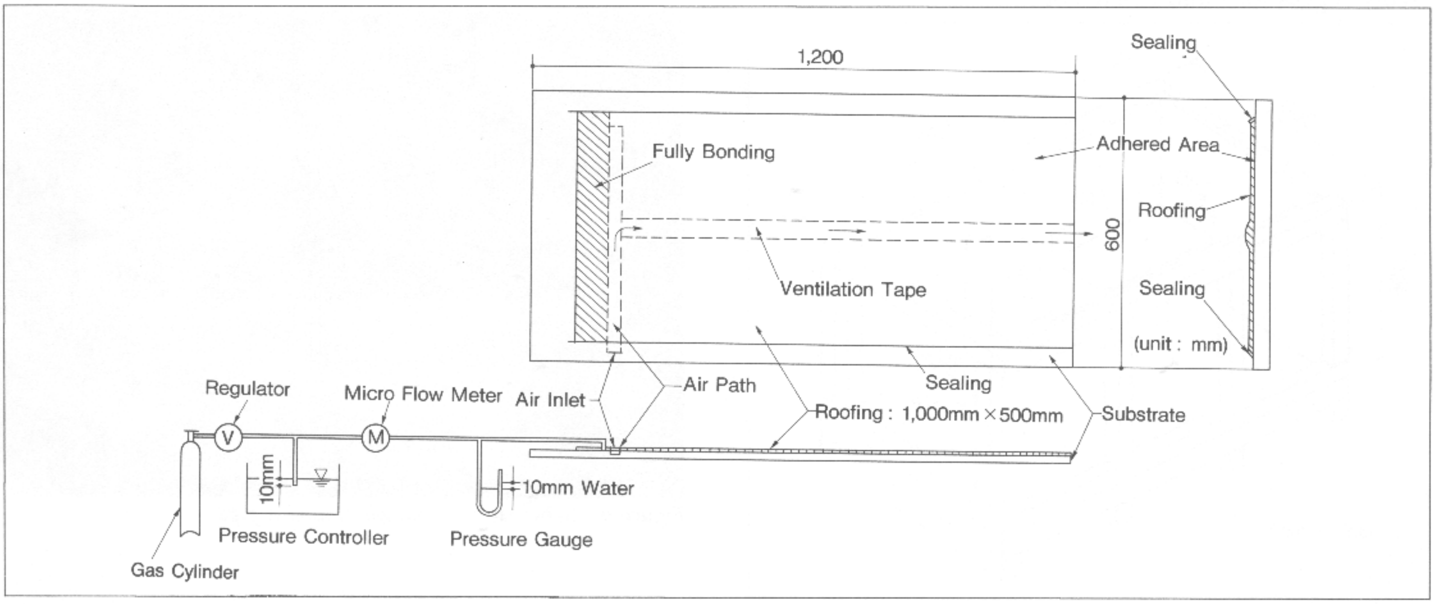

***Figure 7** Apparatus for venting resistance.*

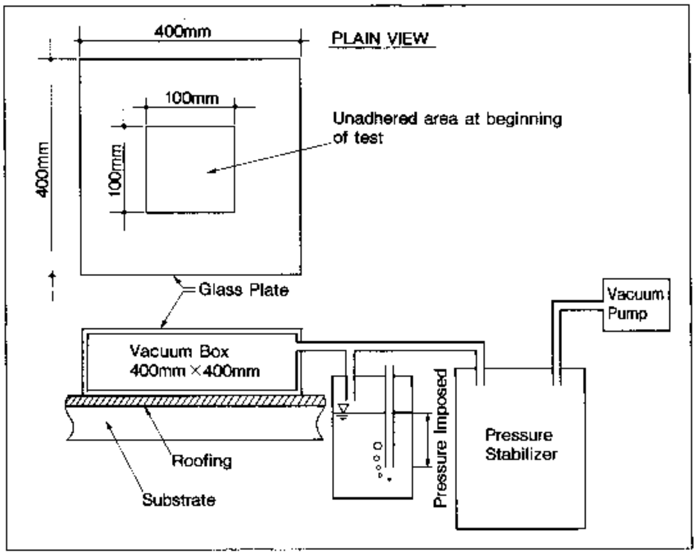

Figure 9 *Apparatus for vacuum resistance.*

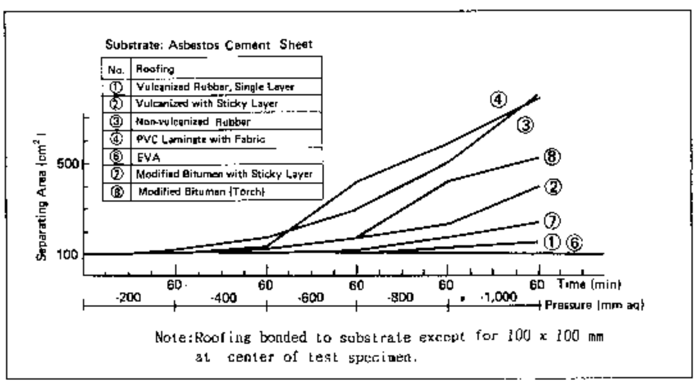

Figure 10 *Vacuum resistance.*

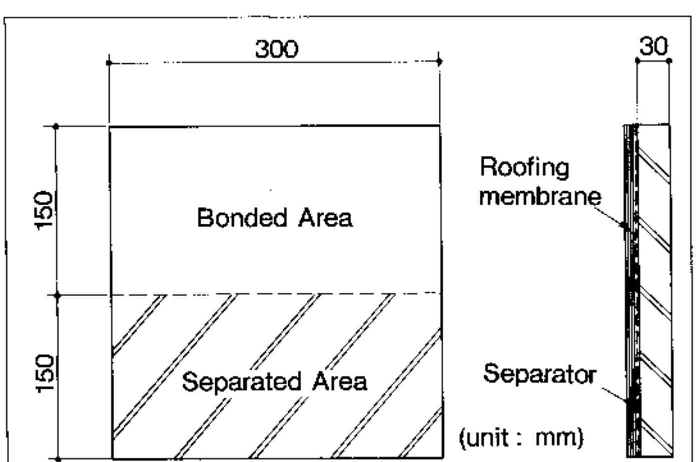

Figure 11 *Slippage test.*

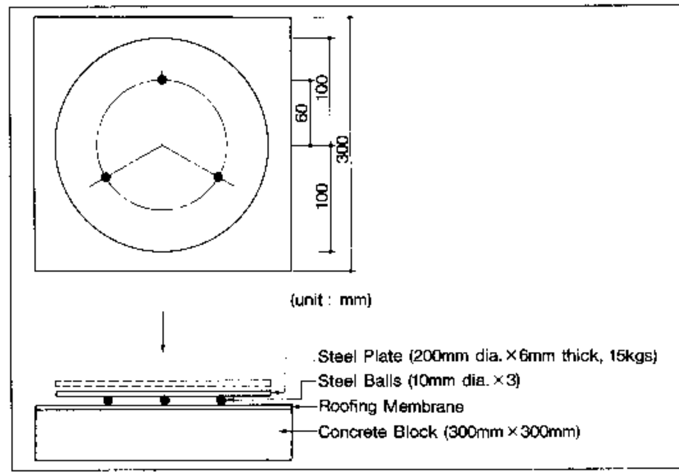

Figure 12 *Static puncture test.*

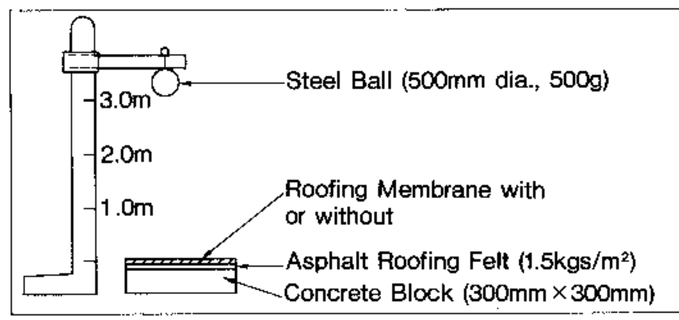

Figure 13 *Dynamic puncture test.*

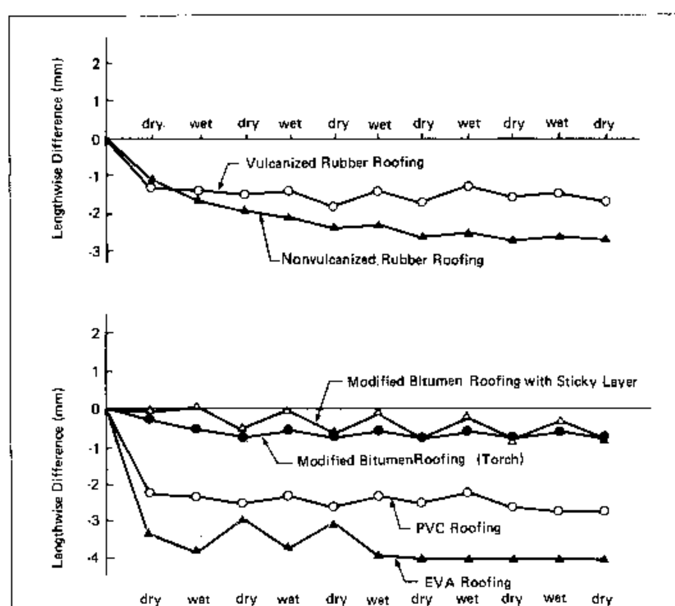

Figure 14 *Dimensional stability.*

No.	Testing Items / Roofing	Water-tightness	Resistance to slippage	Static puncture	Dynamic puncture	Dimensional stability	Resistance to cyclic movement	Resistance to blow-off under suction	Venting resistance between membrane and substrate
1	Vulcanized rubber, EPDM single layer 1.2mm	O	O	O	O	O	O	O	O
2	Vulcanized rubber with adhesive layer, EPDM 1.3mm	—	O	—	—	—	O	O	O
3	Non-vulcanized rubber, EPDM 2.0mm	O	O	O	O	O	O	O	O
4	Polyvinyl chloride, laminated with fabric 2.0mm	O	O	O	O	O	O	O	O
5	Polyvinyl chloride, single layer 1.3mm	O	O	O	O	O	O	O	O
6	Ethylene vinyl acetate, single layer 1.0mm	O	O	O	O	O	O	O	O
7	SBS-modified bitumen with adhesive layer 3.2mm	O	O	O	O	O	O	O	O
8	SBS-modified bitumen, torched 3.5mm	O	O	O	O	O	O	O	O

Table 1 Materials for assesment test.

Substrate	Part	T-joint	Inner edge	Inner corner edge	Outer edge	Outer corner edge	Around pipe
Flat	Water Height	—	300mm	150mm	150mm	300mm	300mm
	Time after pouring	—	0.5 hr	0.2 hr	3 hr	1 hr	1 hr
Box	Water Height	300mm	—	300mm	—	300mm	—
	Time after pouring	24 hr	—	2 hr	—	0.5 hr	—

Table 2 Leakage during watertightness test at critical portions.

Movement (mm)	Stage / Step / Temp.	1 20°C	2 5°C	3 −20°C
0.10 0.20	1	O ——→	O ——→	O
0.25 0.50	2	O ←——→	O ——→	O
0.5 1.0	3	O ←——→	O ——→	O
1.0 2.0	4	O ←——→	O ——→	O
2.5 5.0	5	O ←——→	O ——→	O
5.0 10.0	6	O ←——→	O ——→	O

Table 3 Fatigue test program.

Note: ▬ No Change × Breakdown

No.	Roofings	Stage	1	2	3	4	5	6	Remarks: Appearance	Remarks: Seperating Width (mm)
		Movement (mm)	0.1 – 0.2	0.25 – 0.5	0.5 – 1.0	1.0 – 2.0	2.5 – 5.0	5.0 – 10.0		
		Temp. (°C)	20 / 0 / -20	20 / 0 / -20	20 / 0 / -20	20 / 0 / -20	20 / 0 / -20	20 / 0 / -20		
		Cycle	0	2,000	4,000	6,000	8,000	10,000 – 12,000		
1	Vulcanized Rubber (Single Layer)	without Lap Joint							No Change	7.0
		with Lap Joint								9.0
2	Vulcanized Rubber with Sticked Layer	without Lap Joint							No Change	None
		with Lap Joint								
3	Nonvulcanized Rubber (Single Layer)	without Lap Joint							Breakdown	30.0
		with Lap Joint							No Change	52.0
4	PVC laminated with Fabric	without Lap Joint							No Change	8.0
		with Lap Joint								15.0
5	PVC (Single Layer)	without Lap Joint							No Change	18.0
		with Lap Joint								50.0
6	Ethylene Vinyl Acetate (Single Layer)	without Lap Joint							No Change	21.0
		with Lap Joint								33.0
7	Modified Bitumen with Sticked Layer	without Lap Joint							Wrinkle	None
		with Lap Joint								
8	Modified Bitumen for Torching	without Lap Joint							No Change	77.0
		with Lap Joint								130.0

Table 4 Results of fatigue test.

No.	Roofing	Application to Substrate	Venting Method	
1	Vulcanized rubber, 1.2mm	Fully bonding	Ventilation Tape	Nonwoven, 60mm wide X 1 line
2	Non-vulcanized rubber, 2.0mm	Fully bonding		Plastic film, 40mm wide X 2 line
3	Polyvinyl chloride 2.0mm	Fully boding		Plastic film, 80mm wide X 1 line
4	Ethylene vinyl acetate 1.0mm	Fully bonding		Paper tape, 50mm wide X 1 line
5	Vulcanized rubber, 1.2mm	Fully bonding	Others	Foamed polyethylene with notches for ventilation
6	Polyvinyl chloride 1.3mm	Mechanical fastening		(nothing)
7	Modified bitumen 3.2mm	Fully bonding		Laminated with nonwoven sheet
8	Modified bitumen 3.5mm	Torching		Lamined with perforated sheet

Table 5 Specimens for venting resistance.

Testing Item	Test Method	Criteria
Resistance to slippage	Check slippage at 50°C 168 hr (Step:"S_{50}"), followed by stepping up temp. to 60°C ("S_{60}") and 70°C ("S_{70}").	R_0 : Slip at S_{50} R_1 : No slip at S_{50} R_2 : No slip at S_{60} R_3 : No slip at S_{70}
Static Puncture	Check penetration of roofing under steel ball with 15 kgs load at 50°C, followed by stepping up load to 30 kgs and 45 kgs.	PS-0 : Penetration under 15 kgs load PS-1 : Penetration under 30 kgs load PS-2 : Penetration under 45 kgs load PS-3 : No penetration under 45 kgs load
Dynamic Puncture	Check penetration of roofing and asphalt felt after falling down steel ball of 500g from 500mm height, followed by stepping up height to 1 meter and 1.5 meters.	PS-0 : Penetration at 05.m height PD-1 : Penetration at 1.0m height PD-2 : Penetration at 1.5m height PD-3 : No change at 1.5m height
Dimensional Stability	Measure expansion and shrinkage under dry and wet conditions alternately at 60°C, and calculate difference from original length.	Measure length after heat cycles of five time or after length stabilzation

Table 6 Material evaluation test.

No.	Roofing	Resistance to Slippage	Static Puncture	Dynamic Puncture	
				Roofing	Asphalt Roofing Felt
1	Vulcanized rubber, single layer, 1.2mm	R_3	PS-3	PD-3	PD-3
2	Vulcanized rubber with adhesive layer, 1.3mm	R_3	—	—	—
3	Non-vulcanized rubber, 2.0mm	R_3	PS-0	PD-1	PD-3
4	Polyvinyl chloride, laminated with fabric, 2.0mm	R_3	PS-3	PD-3	PD-3
5	Polyvinyl chloride, single layer, 1.3mm	R_3	PS-3	PD-3	PD-3
6	Ethylene vinyl acetate, single layer, 1.0mm	R_3	PS-3	PD-3	PD-3
7	SBS-modified bitumen with adhesive layer, 3.2mm	R_1	PS-0	PD-3	PD-3
8	SBS-modified bitumen, torched, 3.5mm	R_2	PS-O	PD-3	PD-3

Table 7 Results of material evaluation tests.