T-PEEL TEST FOR APP BITUMINOUS MEMBRANE JOINTS

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On the basis of experimental tests, this study demonstrates the insignificance of the T-peel test in evaluating the performance of APP modified bitumen membranes for single-layer or mechanically fastened roofing systems. The quality of the weld is the only characteristic that influences the performance. It is practically impossible to standardize, for different products, welding in a way to obtain reproducible results. The influence of coatings, reinforcements, temperature testing and operator is negligible.

Only a "good" weld makes the results reproducible, but what is considered "good?"

KEYWORDS

Atactic polypropylene (APP), building, joint, mechanically fastened system, membranes, polymer modified bitumen, roofing, single-layer, styrene-butadiene-styrene (SBS), T-peel test, waterproofing.

INTRODUCTION AND OBJECTIVES

In the last few years, numerous scientific papers[1-6] have shown that membrane joints using modified bitumen with styrene-butadiene-styrene (SBS) have had more resistance than those using modified bitumen with atactic polypropylene (APP) when determining joint resistance by peeling at 180 (T-peel test).

When using the classic tensile stress method (lap-shear test), there was no significant difference in joint resistance between the SBS and APP membranes. This statement has been confirmed by more than 20 years of work assessing the polymer (APP or SBS) modified bitumen membranes.

Note that in the case of non-reinforced membranes based on polymers (EPDM, butyl, etc.), the only possible and practical way to determine joint resistance is by T-peel testing due to the elevated elongation of the products, and because the joints are formed by adhesion (gluing). In the case of PVC-based membranes, both methods give acceptable results, even though peeling values are 50 percent of those obtained by tensile stress.

A theoretical explanation of such results for mechanically fastened roofing systems is that when the membranes' longest dimension is nailed to the support and the adjacent sheet is welded to the first, stresses of peel and shear may be formed in the joints due to dynamic action of the wind. (See Figure 1.)

In Union Europeenne pour l'Agrement Technique dans la Construction (UEAtc) directives for the assessment of waterproofing systems, the T-peel test was an acceptance test both for single-layer and mechanically fastened systems.[7] The minimum acceptable values for single-layer systems are:

- 40 N/50 mm (4.6 lbf/in) at nonaged status
- 25 N/50 mm (2.9 lbf/in) after aging of 30 days at 80°C.

For mechanically fastened systems, the minimum acceptable values are:

- 40 N/50 mm (4.6 lbf/in) both at nonaged and aged status.

This paper will reinforce the poor performance of APP modified bitumen membranes when using the T-peel test, its vital dependence on extrinsic (operative) parameters that are difficult to control and, for mechanically fastened systems, the way to overcome the problem with a correct application procedure where the peel stresses are not present.

EXPERIMENTS

Experimental setup

In an initial series of tests, the authors observed the behavior of the joints tested at T-peel and those tested at lap-shear. Both were tested at a "new state" as well as those aged at 80°C (176°F) for 30 and 60 days.

In the second series of tests, the authors studied the correlation between the polymer modified bitumen (coating medium or compound) and the reinforcement on the behavior of the joint achieved by T-peel on "new state" and those aged at 80°C (176°F) for 30 and 60 days.

The third series of tests examined the influence of the quality of the welding and the temperature test on the joints behavior in T-peel.

Membranes

In the first set of trials, 12 membranes in current production (eight Italian and four Dutch) were used. Membranes 1, 2 and 3 were accompanied by a technical warranty issued by ICITE (Istituto Centrale per la Industrializzazione e la Tecnologia Edilizia del Consiglio Nazionale delle Ricerche). Membranes 7, 8, 10 and 11 were accompanied by a CGT (Certificaat van Technische Goedkeuring) certificate issued by the Dutch BDA INTRON (Verenigde Instituten voor Certificatie en Attestering). The other membranes are not accompanied by any noteworthy certificate.

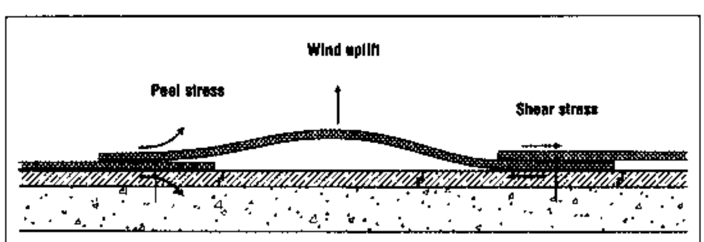

Table 1. Peel and shear stresses on the joint caused by wind action.

In the second series of trials, a number of membranes were produced ad hoc using two different types of polymer modified bitumens (compounds) and six different types of reinforcements.

In the third series of trials, there was a search to find the influence quality of welding and testing temperatures on the final results.

In Table 1, the principal characteristics of the first series of membranes relative to each polymer modified bitumen (compound), to each reinforcement and to each membrane are listed. All these characteristics were determined according to methodologies envisaged by UEAtc Special Directives for the assessment of reinforced waterproof coverings in atactic polypropylene (APP) polymer bitumen.

The reinforcements are classified in the following way:

A: TNT (non-woven) polyester, spunbond, thermally fixed (slightly calendered)

B: TNT (non-woven) polyester, spunbond, bonded and needlepunched

C: TNT (non-woven) polyester, spunbond, thermally fixed (calendered)

D: TNT (non-woven) polyester/polyamide, spunbond, thermally fixed (calendered)

E: TNT (non-woven) polyester, short fibers, needlepunched and bonded

W: double reinforcement, glass felt and TNT (non-woven) polyester, spunbond, needlepunched and bonded

Certain data relative to the polymer modified bitumen (compound) and to the membrane, for products not of Italian origin, are not available because they cannot be obtained with sufficient precision from the final product.

In the second series of trials, compounds 3 and 6 were chosen, purely for operational reasons, while the following reinforcements were chosen:

compounds 3 and 6	type B	180 g/m^2 (0.037 lb/ft^2)
	type C	160 g/m^2 (0.033 lb/ft^2)
	type B	150 g/m^2 (0.031 lb/ft^2)
	type D	135 g/m^2 (0.027 lb/ft^2)
compound 3	type E	250 g/m^2 (0.051 lb/ft^2)
compound 6	type E	200 g/m^2 (0.041 lb/ft^2)

In the third series of trials, three membranes were considered: 2, 3, and 11, which were previously considered.

Test specimen preparations

The samples are welded with a Sievert Matic 3536 propane gas burner with 7.5 Kw (25,600 BTU/hr.) heating power with a welding speed of about 300 mm/min (12 in/min). On the welded area, pressure was applied by rolling a 100-mm-(4-inch-)diameter iron cylinder (weighing about 30 Kg [66 lbs.]).

The welding was done on membrane pieces not less than a meter in length.

After welding, the specimens were placed in an environment at 23°C ± 2°C (73°F ± 3°F) for at least 7 days before being tested.

For the junctions to be tested at T-peel, pieces of membrane were juxtaposed, with their upper face in contact with the opposing lower face, selvedge against selvedge, interposing a layer of anti-adhesive aluminium 50 mm (2 inches) long at one edge, before starting to weld. For the joints to be tested by lap-shear, the pieces were juxtaposed for 100 mm (4 inches) lengthwise before welding. Twenty-four hours

MEMBRANES N°	1	2	3	4	5	6	7	8	9	10	11	12
Membranes characteristics												
Mass per unit area[Kg/m2]	4	4	4,2	3,8	4,6	4,03	3,7	3,9	4,31	4	4,25	4,3
Thickness[mm]	4,01	4	4,05	3,6	4	3,95	3,9	3,65	4,05	4	3,95	3,3
Reinforcement position	1/3 up	1/3 up	1/3 up	1/3 up	1/3 up	1/3 up	1/3 up	1/3 up	1/3 up	1/3 up	GF* up	1/3 up
Cold flexibility[°C]	-16	-15	-16	-10	-10	-12	-10	-10	-8	-5	-10	0
Tensile strength at break T[N/5cm]	710	660	646	670	570	650	765	786	663	765	600	440
Elongation at break T[%]	44	49	50	40	45	49	46	56	51	37	43	43
Upper side surface finishing	sand	sand	talc	sand	sand	talc	sand	sand	talc	sand	talc	sand
Lower side surface finishing	PE film	PE film	PE film	PE film	PE film	PE film	PE film	PE film	PE film	PE film	talc	PE film
Dimensional stability[%]	≤0,5	≤0,5	≤0,5	≤0,5	≤0,5	≤0,5	≤0,5	≤0,5	≤0,5	≤0,5	≤0,2	≤0,7
Polymer modified bitumens characteristics												
Ring and Ball[°C]	150	151	151	150	152	152	150	152	144	149	151	140
Penetration at 60°C[dmm]	136	96	137	90	62	140	114	121	120	102	116	59
Cold flexibility[°C]	-18	-17	-20	-12	-12	-14	***	***	-10	***	***	-2
Bitumen[%] **	69	71	69	70	61	69	***	***	65	***	***	43
Polymer [%] **	26	26	26	22	19	22	***	***	20	***	***	13
Filler[%]	5	3	5	8	20	9	5	12	15	10	13	44
Reinforcements characteristics												
Mass per unit area[Kg/m2]	180	180	180	150	160	180	***	***	180	***	50+150	160
Tensile strength at break T[N/5cm]	510	496	490	470	411	500	***	***	480	***	***	325
Elongation at break T[%]	30	37	38	30	34	35	***	***	34	***	***	40
Reinforcement type	A	B	B	C	B	B	C	B	B	D	W	E

*Table 1. Main characteristics of membranes, polymer modified bitumens and reinforcements (*glass felt, **manufacturers data, ***unavailable data).*

after welding, specimens 50 mm x 500 mm (2 inches x 20 inches) were taken for the T-peel tests and specimens 50 mm x 300 mm (2 inches x 12 inches) were taken for the lap-shear tests.

T-peel test

The marginal sides of the specimen were opened, in the area where the anti-adherent material was located, about 50 mm (2 inches) and inserted into the grips of an Instron testing machine. They are then subjected to tensile speed at 100 mm/min (4 inches/min). The force of peeling is recorded in relation to the distance between the grips.

From data obtained from the graph, the first and last 25 percent was not considered. The average force per unit width was calculated from the remaining data. The "useful" zone of the graph has to be equivalent to at least 150 mm (6 inches) of the effective joint. Five samples were taken of each trial and the arithmetic mean of the three closest values was considered. The discharge of the first and last 25 percent of the graph was due to the significant difference in the mesaured values with respect to the mean value in the central part of the graph (Figure 2). Also see the ISO Standard 6133-1981, Rubber and Plastics: Analysis of multi-peak traces obtained in determination of tear strength and adhesion strength—Method B and C. Only three of the five results were considered on the basis of the UEAtc directive[7] that recommends testing three samples.

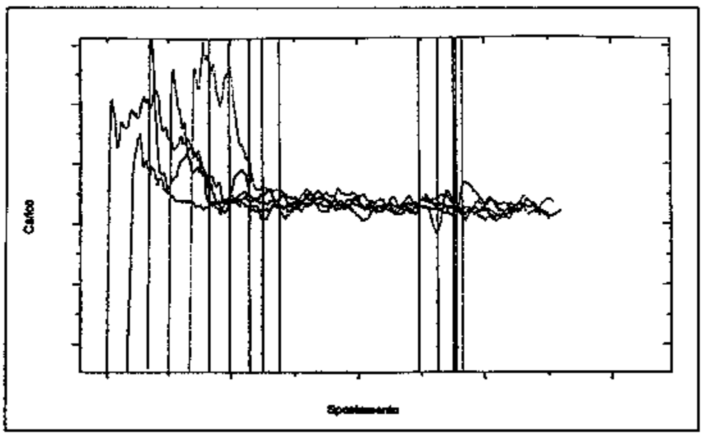

Figure 2. Typical graph of T-peel test on APP modified bitumen joints.

Lap-shear test

The edges of the sample were inserted into the grips of an Instron testing machine so that the useful zone between the grips is 200 mm (8 inches). The tensile speed was 200 mm/min (8 inches/min). Five samples were taken for each trial and the arithmetic mean was taken for the five values. The UEAtc directive[9] recommends testing five samples.

Welding quality

The welding was done by three different operators, allowing a proper evaluation of the welding quality. Each operator welded three samples: in the first welding, the steps were those hither described at their best; in the second, there was less insistence with the torch; and in the the third sample, the membrane was heated extensively. By visual appearance, all the samples seemed perfectly welded.

Trial temperatures

The influence of the temperature of the trials was determined by conditioning the samples for 24 hours at different temperatures and conducting the T-peel test at the temperature at which the sample was maintained. The temperatures chosen were 21°C, 23°C, and 25°C (70°F, 73°F, 77°F), all of which were ±0.5°C (1°F).

The authors wanted to investigate the tolerance of the standard test temperature with this test. The standard test temperature was 23°C ± 2°C (73°F ± 3°F). There are those who affirm that 2°C (3.6°F) is a significant difference for plastic materials. Of course, a difference of 5°C (9°F) or 10°C (18°F) in the test temperature creates extremely different results.

DISCUSSION

The results obtained are found in the following tables :

- Table 2 depicts the results of the T-peel tests and lap-shear tests on the joints of the first series of membranes, both new and "aged." The values are the arithmetic means of the three closest values out of five for the T-peel test and of the five out of five for the lap-shear test.
- Table 3 shows the correlation between polymer modified bitumens (compounds) and reinforcements for T-peel tests on joints from the second series of membranes, new and "aged." All of the values are arithmetic means of the three closest values out of five.

Membrane N°	1	2	3	4	5	6	7	8	9	10	11	12
Joints resistance in T-peel [N/5 cm]												
new [N/5cm]	25,6	47,7	48,2	15,6	22,7	53,6	42,3	44,1	32,7	30,9	71,3	22,2
after 30days at 80°C	19	41	27,9	8	26,2	13,1	23,4	13,9	30,2	21,5	64,1	23,9
after 60days at 80°C	19,3	38,1	22,7	7,7	26,2	11,9	16,7	6,3	26,5	22	38,9	23,6
Joints resistance in lap-shear [N/5 cm]												
new	578	726	643	536	597	590	730	707	707	840	593	400
after 30days at 80°C	560	707	572	425	592	518	**	**	667	**	587	437
after 60days at 80°C	526	693	554	527	525	490	**	**	612	**	**	402

*Table 2. Joints resistance of the membranes tested in T-peel and lap-shear (**unavailable data).*

Membranes made with polymer modified bitumen 3					
Reinforcement type and mass per unit area	B-180g/m2	C-160g/m2	B-150g/m2	D-135g/m2	E-250g/m2
new	52	28	41	47	45
after 7days at 80°C	46	28	34	45	34
after 14days at 80°C	34	23	32	28	18
after 28days at 80°C	26	20	35	29	24
Membranes made with polymer modified bitumen 6					
Reinforcement type and mass per unit area	B-180g/m2	C-160g/m2	B-150g/m2	D-135g/m2	E-200g/m2
[N/5 cm]					
new	61	57	52	61	70
after 7days at 80°C	35	28	49	31	49
after 14days at 80°C	19	27	26	18	30
after 28days at 80°C	13	12	18	16	21

Table 3. Correlation between polymer modified bitumen and reinforcement on joints resistance tested in T-peel.

Membrane N°	2	3	11
[N/5 cm]			
T = 21°C±0,5°C	47,13	48,63	50,13
T = 23°C±0,5°C	43,07	42,31	44,31
T = 25°C±0,5°C	47,1	44,01	63,71

Table 4. Relation between test remperature and joints resistance tested in T-peel.

Membrane N°	2		3		11	
	Singular values	Mean	Singular values	Mean	Singular values	Mean
Low heating						
Operator 1	21,66		20,32		16,03	
	26,61	23,99	23,83	21,49	34,58	22,29
	23,72		20,34		16,28	
Operator 2	24,07		19,63		31,43	
	20,53	20,18	20,14	19,8	33,15	33,05
	15,95		23,35		34,59	
Operator 3	30,04		no test		30,3	
	27,28	26,68	no test		18,23	22,39
	22,72		no test		18,66	
Strong heating						
Operator 1	22,97		30,25		no test	
	26,76	26,28	29,17	27,38	no test	
	29,12		22,72		no test	
Operator 2	21,71		30,96		no test	
	26,08	25,8	29,15	27,71	no test	
	29,61		23,04		no test	
Operator 3	30,84		23,54		no test	
	23,91	24,82	23,17	23,3	no test	
	19,71		23,19		no test	
Optimum heating						
Operator 1	50,87		59,14		46,22	
	43,95	47,13	61,59	62,39	51,39	47,37
	46,58		66,44		44,51	
Operator 2	49,41		54,56		80,23	
	38,43	43,06	60,47	58,11	46,37	56,21
	41,36		59,3		42,03	
Operator 3	48,29		44,94		75,9	
	45,86	47,1	60,92	56,29	40,72	63,71
	47,15		63,01		74,52	

Table 5. Influence of welding temperature on joints resistance tested in T-peel.

- Table 4 illustrates the influence of temperature variation on the T-peel tests on the third series of joints only on new samples. All values are arithmetic means of the three closest values out of five.
- Table 5 depicts the influence of welding temperature on the T-peel tests. All the values are those of single trial and not average values.

From the results in Table 2, it can be observed that all the samples, except number 12, had sufficiently homogeneous results satisfying the requirements of the UEAtc directives[9] for joints tested at lap-shear (>500 N/50 mm [57 lbf/in.]). This was not so for the joints tried at T-peel, where only 2, 3 and 11 gave sufficiently acceptable results. The UEAtc requirements[7] are >40 N/50 mm (4.6 lbf/in.) for the new and >25 N/50 mm (2.9 lbf/in.) for aged at 80°C (176°F) for 30 days. The remaining results were dispersive. Theoretically (Table 1 data), all of the examined products, except number 12, should have given satisfactory results.

Table 3, shows the influence of reinforcements. Polymer modified bitumen 3, used in membrane 3, is a very good compound, while polymer modified bitumen 6, used in membrane 6, is of lower quality. Quality is determined by the capabilty to withstand heat aging. The membrane made with compound 3 withstood the T-peel test, except where the reinforcement was 160 g/m² (0.033 lb/ft²) (reinforcement C). The membranes made with compound 6 never adequately withstood the test, as evidenced by the relatively low peel strengths after heat aging for 28 days. Therefore, it is evident that the reinforcement plays only a marginal role in the results.

Table 4 reflects the influence of the temperature on the behavior of the joints. The standard testing temperature is 23°C ± 2°C (73°F ± 3°F). The highest and lowest values of temperature were chosen in the range of standard temperature. The specimens were conditioned at the test temperature for 24 hours. During the test, the specimen temperature was monitored by a thermocouple in close contact with the specimen itself. The temperature variation was less than 0.5°C (1°F).

From the results it is possible to see that a temperature variation of 4°C (7°F) does not significantly influence the joints resistance.

Table 5 shows how the heat intensity of the weld influences the joints resistance. The values relative to membrane 11, welded with intense heat, are not reported because the membrane has two reinforcements, one of which (glass felt) can clearly be seen on the surface. Elevated heating destroys it.

If the results are examined individually, it seems as though the operator is not a determining factor. In fact, the average values of each single group of results are comparable between the three operators. The greatest differences are found when examining the results related to product heating during welding.

It may be observed that when the sample is slightly heated, the values obtained are very low. Furthermore, there is always a delamination of the specimens at the interface of the two membranes. When the sample is heated significantly, the values obtained are still very low, but the delamination always occurs on the plane of reinforcement. The values obtained from the optimum welds are at a higher and more significant level; the delamination nearly always occurs inside the polymer modified bitumen, but data scatter between operators is very high. Certain maximum values for a given operator and compound are double those of the minimum ones for another operator.

At present, the authors are still unable to establish certain parameters to ensure that the best quality welding occurs; certain compounds must be heated much more than others. The authors must continue to conduct welding trials for the T-peel tests in order to identify, for each product, the best welding conditions.

CONCLUSIONS

From the results given previously, the authors conclude that the test for determining resistance of T-peel is scarcely reproducible because the quality of the welding strongly influences and determines the results to the extent that it questions the validity of such a test for APP modified bitumens, especially if that test is an acceptability test for the assessment. Conversely, in the past 30 years millions of square meters of APP modified bitumen membranes were applied with very good results.

Actually, since the authors were unable to assess the effectiveness of the welding prior to the test, it is difficult to give significance to the test method. Only a large number of similar test data may give rise to significant results. Furthermore, applying a roofing membrane directly on (mechanically fastened or not) thermal insulation is not a correct procedure. There must always be an interposing layer between a *fractioned or mobile** support and a waterproofing membrane, and the waterproofing membrane must be totally adhered on that interposing layer to provide a durable system.

A proper roofing system must be composed of a fractioned support, such as a thermal insulation, a continuous layer which cancels the effects of the insulating panels' borders, and a roofing membrane. This continuous layer should be a roofing membrane, not necessarily of high quality and not assuring the watertightness, onto which the final membrane should always be totally adhered.

For mechanically fastened membranes, if the insulating panels are nailed across the continuous membrane, there is a continuous and uniform layer available on which to weld the final membrane, further ensuring a professional and much more efficient adherence. The results obtained from this type of system would be far more successful than those obtained with the membrane laying directly on the insulating panels and then mechanically fastened to the roofing membrane, both with regard to resistance against possible wind action eliminating or reducing the peel stresses at very low values and to the durability of the final product.

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**A "fractioned or mobile support" is a support layer made with insulated boards or panels, or concrete slabs, that may move by the temperature effect with respect to the waterproofing layer.*