RECOMMENDED APPLICATION TOLERANCES FOR BITUMINOUS BUILT-UP ROOF MEMBRANES

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Over the past century, bituminous built-up roof membranes have been constructed with no universally accepted application tolerances. Without specific criteria available to assess membrane performance with different material quantities applied under different conditions, it has been to the manufacturer's advantage to use a "sliding scale" in judging acceptability of roof membranes. In today's litigious society, with engineering properties and evaluation of system capabilities becoming courtroom controversies, the industry needs an equitable basis for judging acceptability of built-up roofing membranes. These tolerances must not only represent practicably attainable standards of workmanship; they must also assure satisfactory membrane performance as demanded by owners, roofing consultants, and materials manufacturers. These goals appear feasible.

Though the list of items may later be expanded, for this initial effort, we have set suggested tolerances for the following:

- Insulation board joint gaps
- Elevation differences of adjacent insulation boards
- Interply bituminous mopping weights
- Percent interply mopping voids
- Felt headlaps
- Embedded aggregate weight

Insulation board joint gaps

To serve as a suitable substrate for a built-up membrane, insulation boards must be applied with limited horizontal gaps between adjacent boards. To reduce the threat of membrane puncture from aggregate forced into the membrane by foot traffic, dropped tools, etc., a tolerance of 3/16-in. maximum has been suggested, apparently derived from the requirement in ASTM D1863[1], "Standard Specification for Mineral Aggregate Used on Built-up Roofs," which limits the aggregate passing a No. 4 (i.e., 3/16-in.) sieve to a 0-15% range. Thus 85% of the aggregate should be larger than 3/16-in. and should bridge across a 3/16-in. unsupported area in the substrate. Choke action of varied stone gradations also helps to distribute point loads of individual stones on the roof membrane surface.

Since manufacturing tolerances of some insulation boards allow ± 1/4-in. in linear dimensions, combinations of materials ± 1/4-in. may result in a gap between insulation boards approximating 1/2-in., which would generally be considered unacceptable. Friable insulation boards may have corners damaged during shipment or application. Damaged corners could result in areas of unsupported roofing membrane in excess of 1/2-in. at board joint junctures. Any of these conditions may result in puncture damage of the bituminous roofing membrane because of unsupported membrane areas.

The suggested tolerance for insulation board joint gaps is 3/16-in. Any voids in excess of 3/16-in. should be filled with insulation material.

Insulation surface elevation substrate

Variations in elevation between insulation boards at joints in excess of 1/8 in. have proven to be troublesome in that reinforcing materials bridge over the step, resulting in an area of unsupported roofing membrane along the insulation joint. Waterproofing bitumen may fill voids less than 1/8 in. during application, but probably will not provide a "leveling" effect over elevation changes in excess of 1/8 in. This condition generally results in membrane ridging and/or flexural damage of the membrane during application or later under the weight of heavy mechanical traffic. This same criteria should apply to plywood or wood plank decks over which bituminous built-up roofing membranes are applied directly to the deck.

Suggested tolerance for elevation variation in the surface of the insulation/deck substrate at joints is 1/8 in. or less.

Interply bitumen quantities

The significant difference in interply bitumen quantities recommended by various manufacturers confuses roofing mechanics expected to adjust relatively non-adjustable mechanical dispensers to provide precise quantities of a semi-molten material in "uniform" layers. Since the application process in the construction of built-up bituminous membranes is largely repetitive, everyone would benefit from universal agreement on **average** interply bitumen mopping weights and/or total roofing membrane weights.

A recent field test of hand application of reinforcing material indicates significant variations in residual interply bitumen quantities depending on the felt roll weight alone at the time it is rolled into the liquid bitumen. Table 1 shows the expected variation of interply bitumen quantities coinciding with the approximate weight of the roll when the bitumen is applied at the recommended Equiviscous

Temperature. Under diminishing pressure as the felt roll loses weight, interply bitumen mopping weight varies, from about 20% below to about 30% above the mean mopping weight of 20.5 lb/ply/100 sf.

(Test performed by: Twin City Roofing Inc. Wahpeton, N.D. 1982)

Recommendations for interply mopping quantities of 15 major manufacturers of bituminous roofing materials have a narrow range, from 20 lbs. to 28 lbs./square. Recommended tolerance levels of ± 15 percent for interply mopping weights from several manufacturers span a much broader range, from a minimum of 17 to a maximum 32 lb./sq.

In Building Science Series No. 55 issued by the National Bureau of Standards, a minimum interply mopping weight of 15 lbs/sq. in built-up roofing membranes was described as being sufficient to provide adequate waterproofing properties and to provide complete separation between layers of reinforcing materials. Laboratory tests have indicated that excessive interply bitumen quantities increase contraction forces exerted by the built-up roofing membrane and the potential for membrane slippage. Roofing membranes with total bitumen quantities in excess of 200 lbs/sq. produce double the contraction forces of roofing membranes approximating 165 lb/sq. "Heavy", aggregate surfaced built-up membranes may "slip" even on minor slopes of 1/8 in. in 12 in. A maximum acceptable average interply mopping weight of 35 lb/sq. would thus limit contraction forces exerted by the roofing membrane under thermal loading and minimize slippage potential of shingled reinforcing plies.

Suggested tolerances for average interply mopping weights is 24 lb/sq. ± 25 percent, with an absolute minimum of 15 lbs./sq and an absolute maximum of 35 lbs/sq. for the roofing membrane to be considered acceptable.

Interply Bitumen Voids

Voids in interply bitumen obviously create problems in built-up bituminous membranes. There are several types of voids: i.e., "dry" voids (complete lack of interply bitumen in a given area), asphalt voids (voids encapsulated in mopping asphalt), and overlying voids (voids that occur immediately beneath or on top of each other in the reinforced membrane assembly). Dry and overlying voids are especially hazardous in glass fiber reinforced built-up roof membranes, since the porosity of the glass fiber felt allows percolation of water into or through the roofing membrane in areas of overlying or dry voids. Since the nature and type of voids affect the immediate performance of glass-fiber reinforced built-up roofing membranes much differently than they affect organic or asbestos felt reinforced built-up roofing membranes, two criteria are necessary to establish application tolerances for interply mopping voids with various types of reinforcing material.

Criteria for voids set forth in the AFM 91-36[2] stipulate that void area in a 144 sq.-in. test cut should be less than 3 sq.-in. (2%) within any single interply mopping layer for unconditional acceptance of the roofing membrane. Conditional acceptance is suggested when voids range between 3 to 5 sq.-in. within any single interply mopping layer. Voids exceeding 5 sq.-in. (3.5%) within any single interply mopping layer are unacceptable. Criteria set forth in AFM 91-36 make no provision for overlying voids, and under these criteria, an overlying dry void less than 3 sq.-in. between each ply would be considered acceptable. A 3 sq.-in. void in interply bitumen between all plies of the glass fiber reinforced built-up roofing membrane would probably result in immediate leakage through the roofing membrane.

Other data on voids relate to a percent of total interply area. Analysis of a substantial number of samples from built-up roofing membranes indicates that average workmanship under average weather conditions can produce a built-up roofing membrane with less than 3% of the interply area where the overlying felt is not in contact with the asphalt mopping. In observations of poorly performing built-up roofing membranes, samples indicated voids in excess of 8% in the interply mopping layers. Thus, a maximum of 5% voids in interply bitumen through the entire sample—not merely one interply mopping layer—- constitute a seemingly fair criterion for average installations.

Despite the different hazards posed by voids, this 5% figure appears satisfactory both for organic and asbestos-reinforced membranes, on one hand, vs. glass-fiber-reinforced membranes on the other. Interply mopping voids in organic and asbestos-reinforced membranes can grow into blisters or ridges. Though interply mopping voids do not generally produce ridges and blisters in glass fiber reinforced membranes, they do pose the threat of immediate leakage, at worst, or infiltration of moisture into the roof system, at best.

Suggested tolerance for interply bitumen voids is (a) maximum 5% of total sample area (all interply mopping layers); (b) overlying dry voids unacceptable in any roofing membrane; and (c) overlying voids of any type unacceptable in a glass fiber reinforced built-up roofing membrane.

Headlap Tolerance

Criteria for headlap dimension have never been proposed by the roofing industry. Manufacturers publish no recommendations; however, each takes an "unofficial" position in analyzing test samples, usually after problems develop with the roofing system. Historically, manufacturers of built-up roofing materials provided for a 2-in. application tolerance in the overlapping of felt in bituminous built-up roofing membranes. Somewhere over the last 100 years, the 2-in. dimension—intended to provide an application tolerance—has become an absolute dimension.

Testing conducted by Simpson, Gumpertz & Heger, Inc. for the ASTM Committee D-8 indicated no significant loss in tensile strength of an asbestos reinforced bituminous roofing membrane until the headlap became less than 1-in. There was an appreciable "break" in tensile strength of the asbestos membrane as the headlap decreased from 1-in. to 1/4-in.

Testing is currently underway to evaluate the behavior of organic and glass fiber membranes as the headlap is decreased from 2-in. to 0. and tested in accordance with recognized tensile testing standards. Testing of one single headlap does not account for the cumulative effect of installing reinforcing plies in shingle fashion, where missing the laying line consistently by 1/4 to 1/2-in. will result in "dropping" of a reinforcing ply as the shingling process progresses. Unless overlapping corrective action is immediately taken by the applicator, large roof areas may be

short one ply of reinforcing material where headlaps are gone. The four ply built-up roofing membrane is more susceptible to "dropping" of reinforcing plies than the three ply or two ply roofing membrane since the redundancy of the application reduces the allowable tolerance for overlap of the reinforcing plies.

Each job must be assessed for the potential of dropped reinforcing plies since this phenomenon can occur in any installation whether manufacturers' laying lines are used as guides or the applicator "backlines' as a guide for the reinforcing ply installation. The practice of "backlining" tends to eliminate the cumulative effect of decreasing the headlap dimension if the manufacturer's laying lines are off by 1/4 to 1/2 in.

Suggested tolerance for headlap dimension in a single sample of the bituminous built-up roofing membrane is 1-in. minimum. Headlaps less than 1-in. shall be considered unacceptable. This tolerance includes "non-bonded" areas at headlaps where interply bitumen is absent from the full width of the reinforcing material i.e., a minimum of one (1″) inch of the top overlap must be bonded to the ply surface below.

Surfacing Application Tolerances

Since it is relatively easy to ascertain the thickness of a bituminous film on a smooth-surfaced roof or the thickness of a coating applied to the top of a bituminous membrane, most questions regarding surfacing application concern aggregate surfacing installed over built-up bituminous membranes. Pour coat quantities stipulated by manufacturers have historically been 60 lb./sq. for asphalt, 75 lb./sq. for coal tar pitch. Recommended quantities of surfacing aggregate have historically been 300 lb./sq. of slag or 400 lb./sq. of gravel. Some manufacturers' specifications stipulate that 300 lb. of slag or 400 lb. of gravel shall be "embedded" in the 60 lb. or 75 lb. pour coat of bitumen. Laboratory and field testing have proven that it is impossible to "embed" 300 or 400 lbs. of surfacing aggregate into a 60 lb. pour coat of asphalt or a 75 lb. pour coat of coal tar pitch. To provide adhesion of total specified aggregate might require application of double or more of the specified quantity of surfacing bitumen.

Quantity of adhered aggregate is primarily affected by the quantity of bituminous pour coat and, to a lesser extent, by size and quantity of aggregate. Variations in moisture and dust on the aggregate apparently have little effect on the quantity of adhered aggregate within the normally expected 0% to 2% limits imposed by ASTM standards for surfacing aggregate for roofing membranes. Table 2 shows the quantity of aggregate (lb/sq) that can be expected to bond to the roof membrane surface in a 60 lb./sq. pour coat of surfacing bitumen.

Under laboratory conditions the mean adhered aggregate weight increased only from 260 lbs. to 276 lbs. as the total quantity of surfacing aggregate applied increased from 300 to 500 lbs. (a 6% increase in adherence vs. a 60% increase in total available aggregate weight.) Field tests conducted for the National Roofing Contractors Association and results summarized by Chicago Testing Laboratory, Inc. are shown in Table 3. (Tests performed by United Materials Inc., Denver, Co. 1980)

Pour coat bitumen weights ranged from a low of approximately 54 lbs. per 100 square feet to a high of approximately 66 lbs. per 100 square feet. Adhered aggregate weight ranged from a low of approximately 242 lbs. to a high of 360 lbs. Note the correlation between bitumen quantity and adhered aggregate. Significant variations in total aggregate weight and in adhered aggregate weight can be expected in average roof system installations. There is apparently very little correlation between the size or mix of the stone used under ASTM D-448 or ASTM D-1863 specification for roof surfacing aggregate and total adhered aggregate quantity.

Approximately 225 lbs. of any of the recognized surfacing aggregates will provide coverage of the roofing membrane in pour coats as recommended and proven to be achievable. Field testing indicates that higher percentages of adhered aggregate generally accompanied runs with the lowest total quantity of applied aggregate.

Suggested tolerance for surfacing aggregate quantities is a minimum of 225 lbs./sq minimum of surfacing aggregate adhered in the pour coat. Final determination should be by visual reference: aggregate surfacing installation should be acceptable if the entire roof membrane surface is covered with pour coat and adhered aggregate; unacceptable if any areas of the roofing membrane are not covered with pour coat and adhered surfacing aggregate.

Summary

The above referenced tolerances are attainable with average application techniques in the field. There is empirical evidence, substantiated by laboratory testing, that a roofing membrane installed to these suggested tolerances should provide satisfactory service, unless the membrane experiences mechanical damage or physical abuse. Compromises suggested for quantities of material—especially interply bitumen weight—appear readily attainable in the field and yet conservative enough to assure integrity of any roofing assembly supplied by any major manufacturer of bituminous roofing materials.

We have not attempted to prescribe corrective action for deficient conditions for any of the items for which tolerances have been suggested. In most instances, a deficient roofing membrane can be corected prior to application of aggregate surfacing or other surfacing materials. Deficiencies in the roofing membrane should be detected and corrected prior to any surfacing application. Corrective action to insufficient pour coats or insufficient adhered aggregate is relatively simple and can be achieved even after application of the surfacing materials.

General concurrence with the suggested tolerances as outlined herein would provide the applicator of bituminous built-up roofing membranes with readily attainable criteria for acceptable roofing membrane construction. They should provide the owner with indexes for measuring the quality of the roofing assembly. They should provide the consultant with guildelines for recommending acceptance or rejection of the roofing membrane based on observation and representative physical sampling. They should provide the manufacturers with acceptable material quantities to ensure satisfactory service of their individual roofing membrane and reduce confusion on the part of the applicator as to acceptable quantities of material to be installed.

References

1. ASTM D1863 — Standard Specification for Mineral Aggregate Used on Built-Up Roofs
2. AFM 91-36 United States Air Force Manual, Real

Property Operation and Maintenance — Built-up Roof Management Program.

3. NBS BSS-55 Preliminary Performance Criteria for Bituminous Membrane Roofing

Sample No.	1	2	3	4	5	Mean
Roll Weight.	62#	46#	30#	15#	5#	31.6#
Lbs/Square	16.4	17.5	20.3	21.6	26.6	20.5

TABLE 1
Interply Bitumen Weights in Relation to Roll Weight

Total Applied to Aggregate	300	400	500
Pour Coat Quantity/100 SF	60#	60#	60#
Mean Quantity Adhered Aggregate	260	268	276

TABLE 2
Quantity of Adhered Aggregate in 60 lb./sq. Pour Coat

Aggregate No	No.6		No.7		No.67		D-1863		
Run No.	1	2	3	4	5	6	7	8	9
*Type of Aggregate Spreader	M	H	M	H	M	H	H	H	H
Asphalt Weight	53.9	65.9	54.5	57.1	64.1	60.6	61.3	61.1	56.6
**Variability	7.2	26.7	6.7	7.1	19.2	19.1	16.3	5.9	17.4
Total Aggregate Weight	415.0	580.9	395.8	467.8	361.1	360.9	421.0	431.7	436.7
**Variability	50.7	218.2	64.5	168.8	163.9	57.5	258.5	146.2	231.1
Adhered Aggregate Weight	289.6	360.2	262.9	301.2	297.0	315.3	279.4	311.4	242.4
**Variability	36.2	79.7	26.6	59.9	129.2	38.2	39.0	33.6	58.0
Adherence, %	69.8	64.3	66.6	65.1	82.8	87.7	70.3	73.6	59.5
**Variability	0.7	36.8	7.6	10.9	11.1	15.7	32.6	23.7	43.5

*M = Mechanical Spreader; H = Hand Spreader
**Variability = Difference between high and low values for 3 samples

TABLE 3
Gravel Adherence Field Test Summary Table. (Average of three samples per run. Weights expressed as lb. per 100 sq. ft.)