The perfect square: can it be built?

Not if uniformity is ultimate goal

by William C. Cullen

Is a perfect roof possible in the real world?

That depends, of course, on who's judging the results. For some, a perfect roof is one that will produce samples that satisfy the application specifications. If this is the case, most contractors will tell you it can't be done.

But what about building a perfect roof under controlled conditions? Shouldn't it be possible to produce test cut samples that satisfy the application requirements by carefully supervising the workmanship and regulating all the variables? A recent experiment suggests that even in a controlled setting where state-of-the-art application principles are rigidly followed it is impossible to produce a roof that yields representative samples.

Project Perfect Square, as I called the study, was begun to see what level of perfection could be achieved by an experienced crew applying a bituminous membrane under ideal application conditions and close supervision. The researchers were also curious about the validity of test cut sampling and testing procedures that are frequently required in specifications to represent the total roof application.

The opportunity to conduct this project arose during a recent investigation to study the effects of asphalt temperature and viscosity on the application of a built-up roofing membrane under simulated field conditions. The plan called for the installation of a one-square built-up membrane. The roof would be constructed of four plies of asphalt/glass felts, which complied with applicable ASTM material standard specifications, installed in a shingle configuration over a non-nailable deck.

Other requirements for the test roof included hand mopping the interply asphalt at its equiviscous temperature (EVT), which would yield a bitumen viscosity of 125 centipoise. Surfacing asphalt and aggregate were to be applied to a major portion of the test. The asphalt was to be poured from a can and the aggregate was to be shoveled onto the roof. The researchers chose to leave the remaining portion of the test area unsurfaced.

The plan called for the removal of test cut samples from preselected areas using procedures described by ASTM. The samples were to be tested by an independent laboratory in accordance with two ASTM standard test methods[1,2] as modified to determine the following:

- the weight of the interply asphalt;
- the weight of the surfacing asphalt;
- the weight of the aggregate;
- the percentage of aggregate adherence; and
- the area of interply voids

State-of-the-art instructions

Project Perfect Square began on an August day in 1986. The weather conditions in the Chicago area, where the tests were conducted, were excellent; clear, warm and no wind. The roofing crew was instructed to use their best efforts to employ state-of-the-art application procedures while constructing the membrane.

Samples were removed as soon as practical after the crew finished. Six one-foot-square samples, complete with aggregate surfacing, were removed in accordance with procedures defined in an ASTM recommended practice[2] for securing built-up roof samples in the field. In addition, two

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TABLE 1. Membrane component weights measured from Test cut samples

Sample number	1	2	3	4	5	6	Mean	Max	Min	Stdv.
Total membrane	617	649.5	681.3	587	741.5	617.8	649.017	741.5	587	55.572
Aggregate surfacing										
Total	449.9	470.6	504.4	417.2	542.7	449	472.3	542.7	417.2	44.8779
Loose	168.1	203	226.7	117.4	141.5	131.1	164.633	226.7	117.4	42.9579
Embedded	276.8	267.6	277.7	299.8	401.2	317.9	306.833	401.2	267.6	49.7333
Percent embedded	62.2	56.9	55.1	71.9	72.9	70.8	64.9667		55.1	7.93868
Asphalt										
Surfacing	42.6	47	48	50.4	75.9	62.3	54.3667	75.9	42.6	12.4548
Interply	22.2	23.6	22.2	20.6	21.5	17.5	21.2667	23.6	17.5	2.09157

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4-by-40-inch samples were taken from the unsurfaced portion in accordance with the other ASTM recommended practice.[1] Figure 1 illustrates the preselected locations from which the test specimens were removed.

The sampling frequencies for the test roof were much more extensive than procedures generally recommended by ASTM and used in the field. The ASTM standard practice referenced in footnote 1 calls for the removal of one test specimen for each separate roof, plus one additional sample for each additional 100 squares of roof area applied. This is a sample-to-area ratio of about 1-to-10,000. On the other hand, one sample was taken from the Project Perfect Square membrane for every 10 square feet of test area. This represents a sampling ratio somewhat better than 1-to-10.

The samples were packaged and forwarded to a commercial laboratory for testing using the ASTM recommended test method referenced in footnote 2. Table 1 summarizes what the laboratory found. The weights of the respective membrane components given per square in Table 1 were determined by extrapolating the measured weights of the 1-foot-square samples. The table also lists the mean, minimum and maximum values as well as the calculated standard deviation derived from the laboratory's data.

Table 2 reports the total square inches of voids the lab measured in each of the samples' plies. Interply voids were measured to the nearest ½ inch using a transparent plastic grid. The percentage of total interply area affected by voids is also reported. It should be noted here that there are no ASTM standard methods for measuring and reporting interply voids.

What do the numbers mean?

Tables 1 and 2 show wide variations in certain test samples' measurements. Because of this, it would be difficult to say which, if any, of the samples truly represents the entire roof membrane. To take one example, if the total aggregate surfaced membrane weight is projected from the heaviest of the six samples, it would be estimated at 750 pounds per square. If, on the other hand, the lightest sample value is used, the projected weight will be 590 pounds per square. The weight of the aggregate itself could be estimated as either 417 or 543 pounds per square, depending on whether sample 4 or the adjacent sample 5 is selected as the basis for the calculation.

Similar variations will occur if other membrane parameters such as surfacing or plying asphalts are estimated for the entire square based on the laboratory's measurements of these small samples. Obviously, some rather large miscalculations can result from using any one measurement to represent the whole.

The fallacy of projecting values based on relatively small samples is best illustrated by the maximum, minimum and mean findings listed in Table 2. By picking any one of the measurements given, one could support almost any opinion about material quantities of the entire square. Let's turn to asphalt surfacing as an example. Sample 1 indicates that a total of 43 pounds of surfacing asphalt was applied per square. Sample 5, on the other hand, indicates that 76 pounds per square was applied. The difference between these two samples is large enough that it could determine whether the job is considered acceptable or not. According to sample 4, the application did not meet the often-cited specification requirement for a minimum surfacing asphalt application of 60 pounds per square, while sample 5 indicates that sufficient asphalt was applied.

What is the real measurement of the surfacing asphalt for the 50-square-foot area we're interested in? The more correct answer may be around 55 pounds per square, which is the mean value of all six test samples. As we have said before, however, it is more likely that only one test sample would be used to evaluate a 50-square-foot area on an actual roof.

Voids where prohibited

The laboratory's report also shows how difficult it would be to project the total interply void area of a roof from a single one-foot-square sample. Table 2 illustrates the degree of consistency that may be anticipated when an asphalt/glass roof membrane is constructed under ideal conditions. If all six test samples are taken into account, a void area approximating 3 percent of the total 50-square-foot test roof may be estimated. But if only one ply of one sample is looked at, quite a different picture emerges. Voids were found in sample 6, for example, that equaled 7 percent of the total sample area. Again, depending on the criterion used, the choice of sample could determine if the roof passes or fails.

I believe that Project Perfect Square confirms the old cliche that the application of a built-up roof is an art rather than a science in spite of the recent advances in roofing technology. The observations made during the project corroborate the results of the Koppers/NRCA Study (3). They show that experienced roofing crews do not apply a built-up roof with quantitive terms in mind. As the workers mop down the asphalt or shovel out the gravel, they are not concerned with the specific pounds per square of material they are applying. Rather, when they mop down interply bitumen, they intuitively aim for applying bitumen at a consistency that will produce a continuous film of material that will be sufficient to properly adhere the plies and maintain the membrane's waterproofing integrity. When they come to the asphalt and aggregate surfacing, they are concerned most with applying sufficient amounts of aggregate to insure complete membrane protection and sufficient asphalt to embed the aggregate.

Project Perfect Square's results indicate that the asphalt and aggregate components weighed close to amounts real-world job specifications often require. I don't believe this was coincidental. The values that are frequently specified were, in all probability, derived from experience gained from many year's of roof applications that provided roofs that performed satisfactorily. They are not based necessarily on performance aspects of the roof membrane.

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TABLE 2. Interply void analysis of Test cut samples

Interply void (sq. in.)	1	2	3	4	5	6
Ply 1 & 2	3	7	0	3.5	7	10
Ply 2 & 3	1	1	2	4.5	4.5	3
Ply 3 & 4	6	3.5	1.5	3	0	2.0
Total voids	10	11.5	3.5	11	11.5	15.5
Percent voids	2.3	2.7	0.8	2.6	2.7	3.6

Another interesting finding came to light when the the two 4-inch-by-40-inch unsurfaced test specimens were evaluated using non-destructive techniques as described in footnote 1. An examination of the specimens' perimeter edges failed to reveal evidence of interply voids. However, when these identical specimens were actually separated by the ASTM procedure in footnote 2, the same percentage of voids were detected as for the 1-square-foot samples. This clearly indicates different test results from different test procedures can be obtained for identical specimens.

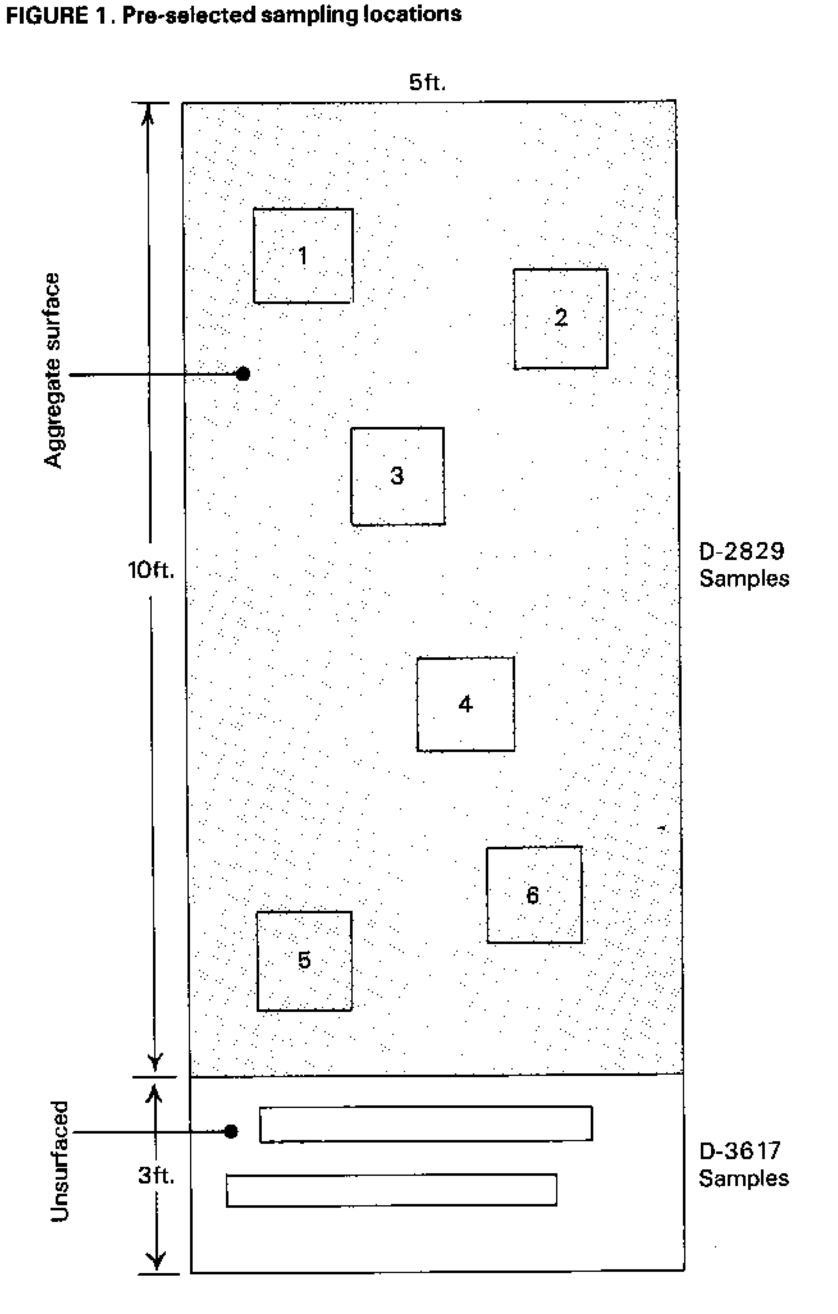
Did Project Perfect Square live up to its title; was it, in fact, a perfect square? The answer must be an emphatic no. As we have seen, the test data showed wide variations between the measured values of the membrane components. If a roof must be uniform to be perfect, perfection was not attained. And, as the area of interply voids indicates, perfect membrane integrity also was not achieved.

Project Perfect Square confirms the old cliche that a BUR application is an art rather than a science.

But even though it was not a "perfect" roofing square, there was agreement among the experts and crew alike that a roofing membrane constructed of similar materials, by a similar crew, under similar work conditions probably would perform satisfactorily for many years in any climate of the United States. Another question raised by the project concerns the relationship of sampling and testing results to on-the-job quality control practices. First, the results point out that the test cut sampling procedures sometimes used in the industry probably do not yield results that are representative of the whole roof area. One sample cannot possibly indicate the quality of a whole day's work or a 10,000-square-foot area applied under field conditions. Even with the increased sampling frequency used in this study, it was not possible to get a clear and consistent picture of the test membrane.

This conclusion is corroborated by the results of the Koppers/NRCA research program. Test cut samples taken during this study also lacked uniformity, leading researchers to conclude that specifying uniform weights for membrane components is not realistic. The study's findings also challenge the validity of using test cut samples as the only quality control parameter for membrane components.

FIGURE 1. Pre-selected sampling locations



The bottom line

Project Perfect Square reaffirmed some of my long-standing opinions about the art of roofing. The following list summarizes the study's key findings.

- The quality of a built-up roofing membrane depends more on good application practices than on the specific quantities of the membrane components specified.
- The quantity of membrane components currently stated in job specifications is based on many years of application experience.
- Test cut sample results probably are not representative of large roof areas and do not necessarily indicate membrane quality.
- Test results for a specific property obtained on identical samples may vary depending on the particular test procedure used in the measurement of the property.

References

1. ASTM D-3617-83, Recommended Practice for Sampling and Analysis of New Built-Up Roof Membranes, *Annual Book of ASTM Standards,* Volume 04.04, 1985.

2. ASTM D-2829-76, Recommended Practice for Sampling and Analysis of Built-Up Roofs, *Annual Book of ASTM Standards,* Volume 04.04, 1985.

3. Temperature and Viscosity Effects on the Application of Coal Tar Products During the Construction of Built-Up Roofing Systems. Koppers/NRCA Research Report, December 1986.