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Duct Tape and Sealant Performance

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Introduction

It’s in garages, kitchens, cars and boats. Books have been written about it. Wallets made from it are sold online. What is this infinitely useful product? Duct tape, of course. Although it serves so many purposes, it is important to understand how duct tape works for its ostensible purpose—to seal ducts.

At the Lawrence Berkeley National Laboratory (LBNL), we have studied the durability and longevity of duct sealants for more than a decade and have created test methods for evaluating these properties. What we found was almost every product intended to be a duct sealant works—except duct tape. In this article, we summarize what we found and describe some of the work we did to evaluate duct tape and other sealants.

The project began in the mid-1990s when California utilities were convinced that sealing air leaks in ducts was a cost effective measure for saving energy and ensuring good distribution of air throughout a building. They were concerned by the many anecdotal reports of duct sealant failures in the field and wanted to be able to recommend or require good sealing methods. They approached LBNL about creating a laboratory test method that would rate or rank duct sealants on their durability.

We developed a test and expected to see a spectrum of results for different sealant products, but what we found surprised us. We found most types of sealants passed our test without any significant failures. These products included mastics, a wide spectrum of tape products with acrylic or butyl adhesives, and aerosol sealants. The only product class that failed consistently, and often catastrophically, was cloth-backed, rubber-adhesive tape—commonly called duct tape.

As with many other building products, duct sealants are rated by Underwriters Laboratory using UL 181B safety standards. These standards are used by many jurisdictions as a requirement for duct sealants. When we began testing, few duct tapes existed that were UL 181B rated, but the ones we tested for sealant durability had similar failure characteristics to unrated tapes.

Since that time, we have focused our efforts at improving the test procedures and trying to solve the problem of why duct tape could pass the UL 181B tests and not have sufficient longevity to be used in many field applications. To address this problem, we carried out several additional studies to understand the performance and durability of various duct sealing approaches.

Background

UL has developed standards for closure systems for use with rigid air ducts and air connectors, and flexible air duct and air connectors; UL 181A and UL 181B, respectively.[1,2] Although these two standards are similar, the most appropriate standard for duct sealing issues addressed here is UL 181B because it applies to field assembled flexible duct systems. The standard covers pressure sensitive tapes (UL 181B-FX), mastics (UL 181 B-M) and fasteners[*] (UL 181 B-C). The Air Diffusion Council[3] has standards providing recommendations for the installation of ducting systems, including the use of two wraps of duct tape and a clamp for mechanical connection over flexible duct core-to-collar joints.

The UL 181B standard only applies to tapes to be used on flex duct core-to-collar connections in conjunction with a strap to mechanically hold the connection together. This limited applicability is important because many building codes reference the UL standard for duct seals without restricting the application to these specific connections.

Six tests are prescribed for pressure sensitive tape: tensile strength, peel adhesion at a 180° angle, shear adhesion, surface burning, mold growth and humidity, and temperature. While the UL tests address some important aspects of sealant performance, they do not adequately address durability issues. For example, the “shear adhesion test” requires duct tape to sustain a specified load without evidence of separation or slippage in excess of $^{1}/_{8}$ in. (3.2 mm) for only 24 hours. UL 181B and the ADC focus on the core-to-collar joint. Empirically, however, it has been observed that the geometrically more complex collar-to-plenum joint is a more significant source of air leakage. It is also common to use the same sealant system (e.g., tape) on both kinds of joints. Thus, it is important to consider the full range of likely applications of sealants when evaluating suitability.

The LBNL test procedures followed typical accelerated aging and durability methods, in which product test samples are prepared in a standard manner and then exposed to closely controlled environmental conditions that represent extreme operational temperatures and pressures expected for residential systems. This means continuously exposing the sealants to hot and cold air temperatures and pressure differences that can occur in real systems. The temperatures we used did not exceed sealant temperature rating limits and were substantially (50°F [27°C]) below those allowed in duct systems by mechanical codes. For typical duct system operation, we would not expect the systems to continually operate at the temperatures and pressure differences that we used. Due to the variability in the operation and exposure to extreme conditions in duct installations our test results are not directly translatable into a field service life. Instead the test procedures are used as a basis for comparison between different sealants.

Two test procedures were used: (1) a durability test that evaluated sealants on duct connections and (2) a baking test that evaluated sealants on sample substrates representative of the materials used in duct systems. The baking test is similar to the temperature test used in UL 181B-FX, but the durability test has no UL analog.

The durability tests evaluated six major types of sealants: (1) tape with vinyl or polyethylene backing with fiber reinforcement and rubber-based adhesive (what we would normally think of as duct tape, and is referred to as such in this article), (2) polypropylene (OPP) tape with acrylic adhesive, (3) foil tape with acrylic adhesive, (4) butyl tape with foil backing and thick butyl adhesive, (5) mastic, an adhesive that dries to a semi-rigid solid, and (6) aerosol sealant, a sticky vinyl polymer that seals leaks from inside the duct system. One-hundred and fourteen samples were tested using these procedures. Thirty-three sealant products were evaluated, 12 of which were UL 181A, 181B-FX or 181B-M listed.

Two types of connections were tested that reflect the majority of connections in duct systems: collar-to-plenum and core-to-collar. The collar-to-plenum joints are typical of a duct branch, splitter box, or a supply or return plenum (*Figure 1*). The collar-to-plenum joint was the most difficult to seal with duct tape because the leaks to be covered are not in a flat plane. The tape must be folded to conform to the joint. The round collar is mated through a circular hole to a flat piece of metal, with a set of flexible tabs that mechanically hold the collar in place with the use of sheet metal screws. The gaps between the tabs leave holes of one eighth to one quarter of a inch (3 to 6 mm) that are significant air leakage sites. All types of sealants were evaluated for this connection.

The core-to-collar duct connection consisted of a 6-in. diameter round collar inside a flex duct core (*Figure 2*). Each sample had two core-to-collar connections: one at each end of a short piece of flex duct core. One of the collars was open-ended for connection to a plenum that supplied hot air. The other collar had an end cap that was internally sealed with mastic. A nylon strap was used to mechanically hold the connection together for most samples. We also tested some unstrapped joints to see if the strap had a significant effect on the seal. Only tapes were evaluated using the core-to-collar connection.

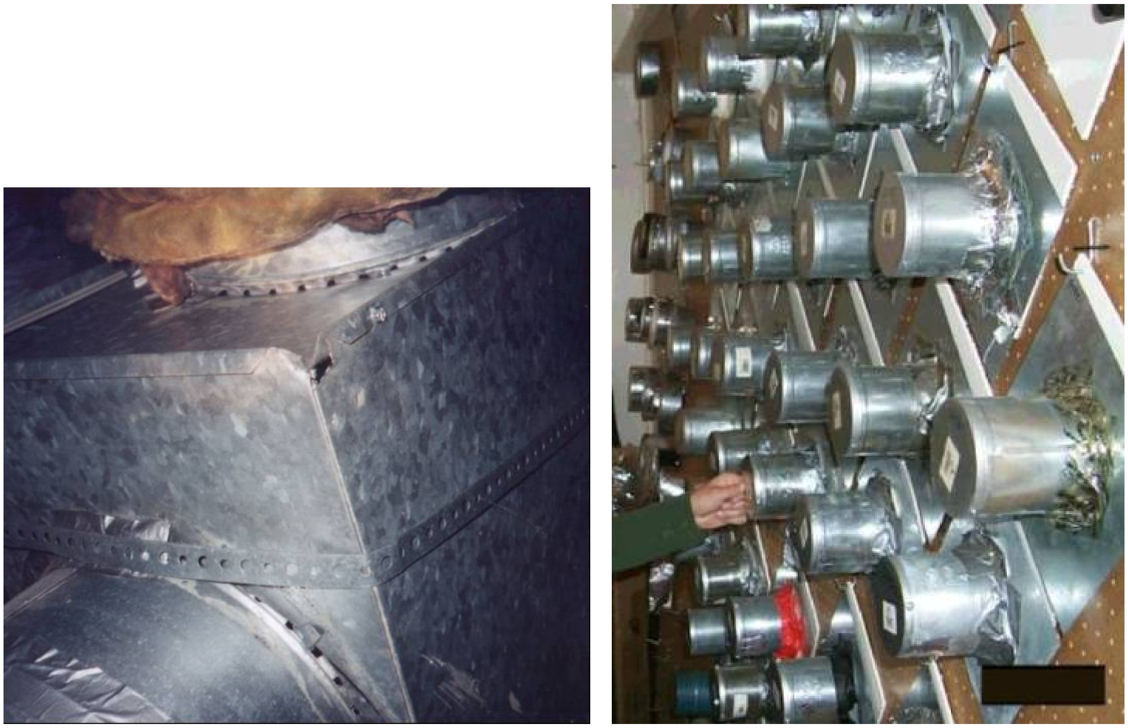

Figure 1. Field observation of a collar-to-plenum connection where the tape sealant has fallen off, and a collection of collar-to-plenum test samples from LBNL testing.

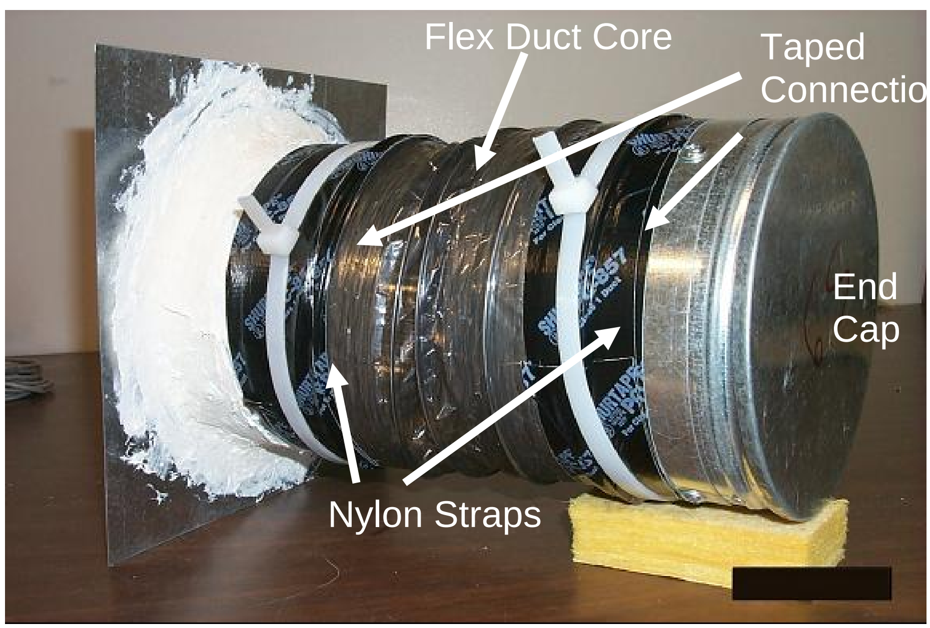

Figure 2. Example of a core-to-collar test sample showing the two taped connections and nylon straps.

Durability Test Procedure

The sealants were tested using an apparatus that maintained a pressure across the sealed joint (*Figure 3*). The surface temperatures of each sample, the air temperature, and the pressure across the leaks were continuously monitored using a data acquisition system that also controlled the temperature in the apparatus.

Figure 3. Samples mounted in the test apparatus.

Air leakage measurements for collar-to-plenum samples were conducted periodically (typically on a monthly or weekly basis) by removing the samples from the test apparatus and making a precision airflow measurement. Failure was said to occur when the measured leakage increased by 10% of the sealed airflow determined before installation in the test apparatus.

For core-to-collar samples, there was no reliable way to measure the air leakage because the flexible duct does not fit uniformly on the sheet metal fitting. In addition, the flexibility of the core and how it is placed around the sheet metal collar can make a considerable difference in the amount of leakage. Therefore, failure was characterized by a combination of the changes in leakage, as well as visual inspection.

The durability and baking tests used the same visual inspection criteria: drying and hardening of the adhesive, shrinking of the tape backing, delamination of the tape layers (backing/fiber/adhesive), and peeling of the tape off the sample.

Durability Test Results

For the collar-to-plenum samples, only duct tapes (cloth-backed rubber adhesive tapes) failed. However, the range of time to failure for these types of tape was large. Some failed in a few days and others failed over several weeks. *Figure 4* illustrates two of the failed collar-to-plenum joint test samples.

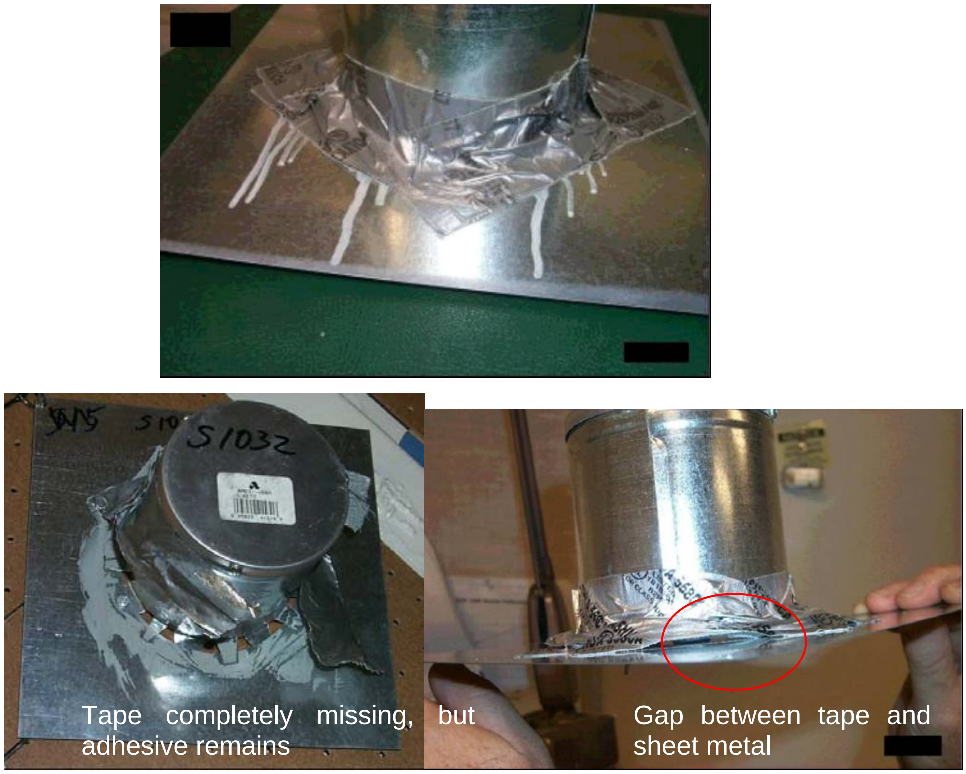

Figure 4. Example failures of the collar-to-plenum joint.

The failure of these samples was due to a combination of factors. Some samples exhibited obvious adhesive failure, with the adhesive flowing out of the seal, or hardening and becoming brittle so that it was no longer sticky. The brittle failures sometimes led to catastrophic failure where the tapes fell off the sample completely, leaving a layer of adhesive on the joint. Delamination was common, mostly because the backing shrank more than the adhesive or the reinforcing mesh. One sample failed even before it was installed in the test apparatus. In this case, the sample was prepared for testing and placed on a workbench in the laboratory for a week. The tape had peeled itself off the joint in an attempt to return to its natural shape.

The test results also showed that higher temperatures were most likely to result in sealant failure. Samples exposed to the cycling temperatures took longer to fail than the heating only samples. No constantly cooled samples failed—including duct tapes. The combination of heat and pressure difference caused more rapid failures than heat alone (as applied to the baked samples). This was because the pressure difference placed a force on the sealant such that it could move if the adhesive failed at high temperatures.

For the core-to-collar samples, the leakage results over the two years of testing showed no systematic increases in leak-age and none of the catastrophic failures seen in our previous studies. Several samples showed leakage reductions and visual observations indicated that this is probably due to the flowing of the adhesive at high temperatures, such that it seals more of the small cracks and leaks as it flows (*Figure 5*). Typical minor deteriorations observed were discoloration, wrinkling, and oozing. The major deteriorations observed were shrinking, peeling, delamination and cracking (*Figure 6*). Like the visual inspections of the UL 181B test, these evaluations are subjective, but they do serve to give a relative rating for each tape. Observations showed that OPP tape had the most deterioration, while foil-butyl tape showed the least deterioration. Although the OPP tape appeared to be almost disintegrated, it still maintained a good air seal. This is because the tape is not being asked to be a mechanical connection, only to seal the gap between the collar and the flex duct.

Figure 5. These samples show oozing of the adhesive at the tape edges.

Strap Failure

One unexpected result of the testing was the failure of the nylon straps. Discoloration of the nylon strapping was observed within one month of the start of testing and the first strap broke after four months. Two different nylon strap materials were used and both showed the same brittle failure. The straps usually failed at the point where the strap passes through the ratchet of the zip-tie mechanism – where the mechanical stresses are greatest. Strap failure is a major problem because mechanical attachment is maintained thereafter only by the duct sealant. If ducts are not well supported, significant mechanical stress can occur to cause the sealant to fail after the strap fails, which in some cases may cause the duct connection to separate.

The materials used for the straps were typical of those used in the field, which have an unknown temperature rating. Product literature from strap manufacturers shows that there are other strap materials that have higher temperature ratings, such as Heat Stabilized Nylon 6/6 for continuous exposure above 185°F (85°C) and TEFZEL® for even higher temperatures, and these straps may have improved high-temperature durability. As an alternative, we recommend metal straps because they will not fail at even higher temperature ranges.

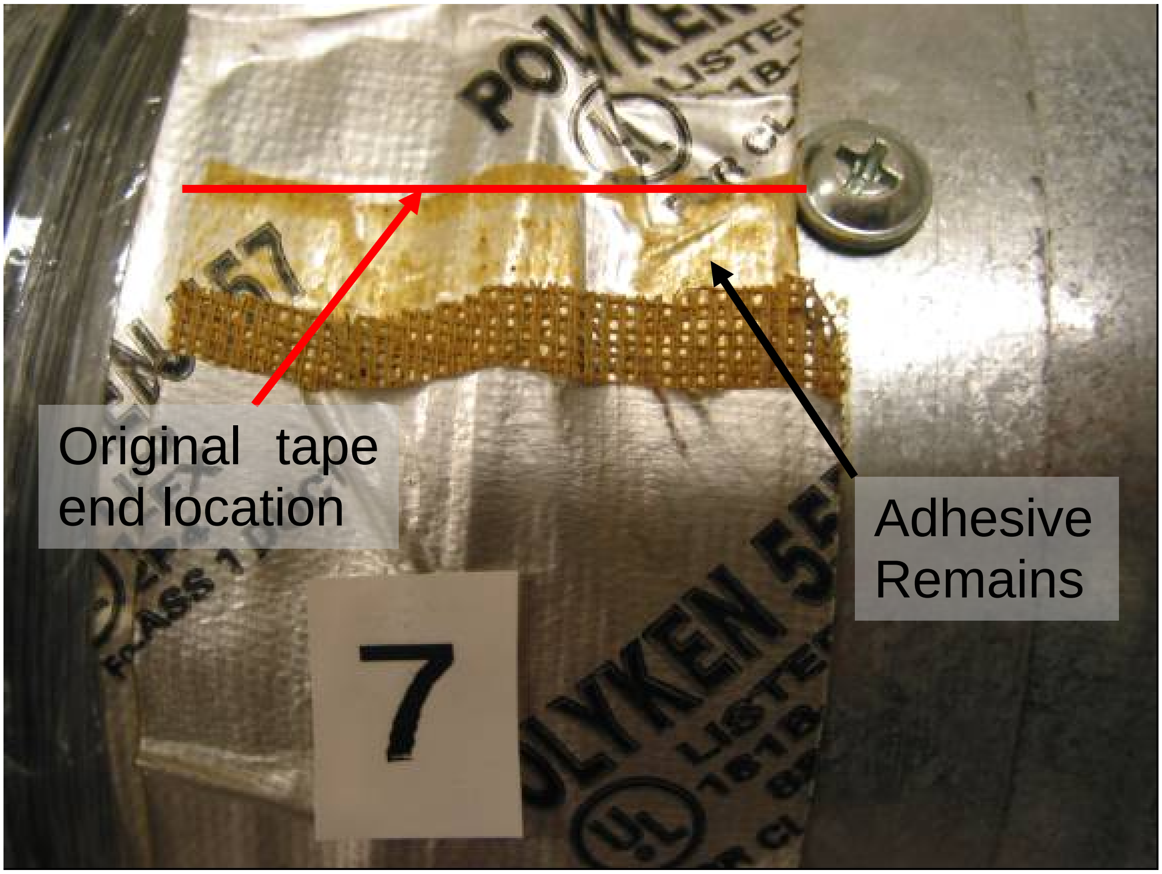

Figure 6. Cloth backed tape sample showing considerable shrinkage and delamination.

Figure 7. The OPP tape showed considerable visual degradation, even though it still provided a good air seal for the core-to-collar samples.

Figure 8. Failed plastic strapping on one of the flexible core-to-collar samples after four months of aging.

UL 181B Revisions for Straps

In 2003, UL 181B was revised to include a new test for fasteners including straps. Products that pass the test are to be marked UL 181B-C. Because LBNL testing started before this new UL strap requirement, we were not able to evaluate the performance of UL listed straps. The tests include tensile strength, smoke spread, heat production, mold growth, tension test (evaluation of the mechanical integrity of the connection), air leakage, and low and high temperature aging.

The most relevant test for longevity is the high temperature test in which the straps are heated to 212°F (100°C) for 60 days. The straps are tested for tensile strength before and after the 60 days and must retain 75% of their initial strength. The tensile testing itself does not occur at high temperature. Instead, the straps are conditioned for 48 hours at 73°F (23°C) and 50% relative humidity before tensile testing at some unspecified temperature. In other words, their performance at an elevated temperature is not evaluated. Instead, the effect of high temperature exposure on material properties is the object of the UL test.

While a good step forward, the new UL test needs some improvement before it can become a good indicator of strap performance. The limitations with the UL test are:

- Straps are not tested in the failure mode that is observed, such as brittle failure in bending. We do not know if the strap materials show greater or lower tensile strength as they become more brittle. Many ductile materials show greater tensile strength as they become brittle. In addition, the straps are not subjected to any strain during the UL high temperature baking. In real applications (and in laboratory testing), the straps are under the influence of combined heat and strain. Without additional testing, we do not know if this is a factor, but in general we would expect that it is.
- Testing is for 60 days only. In the LBNL study, none of the straps failed in 60 days. Testing for only 60 days appears to be insufficient. Given the relatively arbitrary nature of selecting time limit criteria, UL should select an appropriate time limit that differentiates between acceptable and non-acceptable performance.

Baking Test Procedure

In our baking tests the sealants were exposed to heat only, maintaining the tapes at 212°F (100°C) for 60 days. These tests are equivalent to the baking test procedure in UL 181B-FX. Only UL181B-FX tapes were evaluated using the baking procedure. The baking test samples were prepared in two ways. Some samples were the same as for the leakage tests and other baking tests evaluated the tapes stuck to flat substrates rather than to a duct connection. This testing on a flat substrate is how sealants are evaluated in the UL181B test procedure.

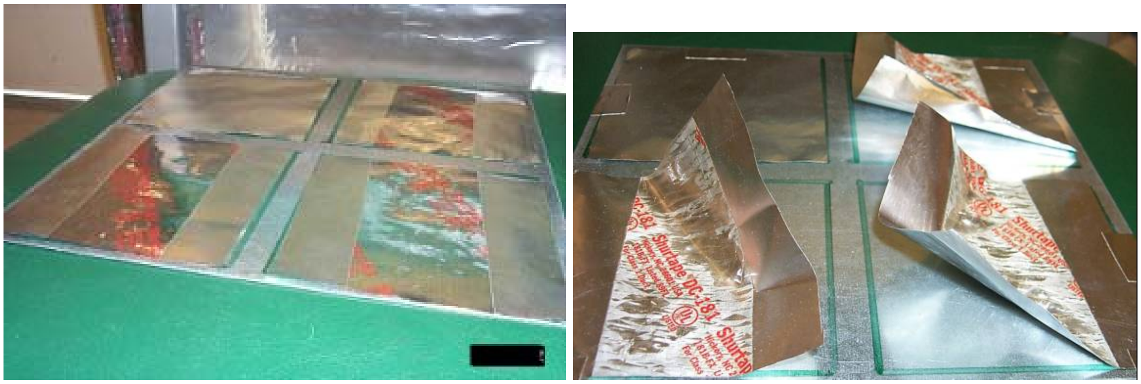

Figure 9. A baking sample before testing (left) and after four weeks of testing (right).

Baking Test Results

Weekly visual inspection of the baking samples showed gradual deterioration in the samples over the 60-day test period. The foil-butyl tape samples showed the least deterioration and the OPP tape showed the most deterioration. All the samples except butyl-foil tape showed significant visual degradation in the baking tests and therefore they failed this test.

Visual degradation may not always be a good predictor of sealant longevity in the field. In some cases, for example, tapes that failed various visual tests actually performed well in the more robust durability test. In other cases tapes which mechanically strong backing may pass some kinds of visual inspections yet fail on the more robust tests.

Conclusions and Recommendations

The results of this work show that care must be taken when selecting duct sealants if long-term durability of the seal is to be maintained. Cloth backed rubber adhesive (i.e., duct) tapes have been shown to be the most problematic of all commonly used sealants. This has been recognized by the California State Energy Code (Title 24) that prohibits the use of cloth-backed duct tape alone as a duct sealant. While duct tapes that fail usually show visual degradation, visually degraded tapes did not always have excessive leakage. Because the UL tests do not sufficiently address durability issues, we recommend the additional use of ASTM E2342-03, “Standard Test Method for Durability Testing of Duct Sealants” that uses a test procedure similar to that used in these studies.

The nylon straps failed in our testing, but no systematic studies have been done across product classes. UL has proposed a new standard for straps, but the protocol for the current UL test does not suggest it is a good indicator of durability. Until a suitable test for strap durability exists, we recommend that only high temperature nylon or metal straps be used.

You can keep that tape with the gray cloth backing and the white rubber adhesive in your tool box or backpack, but if you need something to seal ducts over the long haul, you need to consider something other than the old faithful—duct tape.

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