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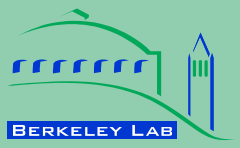

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BERKELEY NATIONAL LABORATORY

Duct Tape Durability Testing

M.H. Sherman and I.S. Walker

Environmental Energy Technologies Division

April 2004

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Executive Summary

Duct leakage has been identified as a major source of energy loss in residential buildings. Most duct leakage occurs at the connections to registers, plenums or branches in the duct system. At each of these connections a method of sealing the duct system is required. Typical sealing methods include tapes or mastics applied around the joints in the system. Field examinations of duct systems have typically shown that these seals tend to fail over extended periods of time. The Lawrence Berkeley National Laboratory has been testing sealant durability for several years. Typical duct tape (i.e. fabric backed tapes with natural rubber adhesives) was found to fail more rapidly than all other duct sealants.

This report summarizes the results of duct sealant durability testing of four UL 181B-FX listed duct tapes (two cloth tapes, a foil tape and an Oriented Polypropylene (OPP) tape). One of the cloth tapes was specifically developed in collaboration with a tape manufacturer to perform better in our durability testing. The tests involved the aging of common "core-to-collar joints" of flexible duct to sheet metal collars. Periodic air leakage tests and visual inspection were used to document changes in sealant performance.

The current study is a continuation of ongoing research at Lawrence Berkeley National Laboratory (Sherman and Walker, 2003; Walker and Sherman 2003; Walker and Sherman 2000; Sherman and Walker, 1998) that has the following objectives and outcomes:

Objectives	Outcomes
Evaluate existing UL 181B-FX rated tape products over two years of testing.	The core-to-collar connections had no significant failures in terms of leakage. Some showed significant visual degradation. The standard nylon straps[1] failed before the two year test period was completed.
Develop a standardized test method for evaluating duct sealant durability (under the auspices of the American Society for Testing and Materials (ASTM)).	An ASTM standard (E2342-03) has been developed that will standardize test procedures and increase reliability of testing.

Key project conclusions based on the 2-year core-to-collar testing presented in this report:

- When properly installed on round core-to-collar connections that do not place any mechanical stress on the joint, the UL181B-FX tapes tested do not show substantial increase in air leakage, but have substantial visual degradation.
- ASTM E2342-03 is a superior test method for determining sealant longevity than the core-to-collar test procedure that formed the majority of testing for this report because it better addresses durability requirements.

[1] The terms "fastener", "clamp", "strap", "drawband", "strapping system" and "clamping system" are all used to described mechanical fastening of flex-duct material to the metal collar. Different references and standards use these terms and we do not make any distinctions between them in this report.

- The new duct tape is an improvement over other cloth-backed tapes, but still fails in collar-to-plenum testing.
- An unexpected discovery of the research was that the standard (non-metallic) core-to-collar clamps have unacceptable high temperature performance. The new UL 181B testing of clamps does not adequately address this issue.

Recommendations:

- At the next appropriate standards revision cycle the following changes should be considered:
    1. The special provisions for cloth back rubber adhesive tapes in Title 24 should be removed and replaced by a requirement that all sealants pass an ASTM E2342 test for a period of at least 60 days[2].
    2. Straps must be rated for continuous use at a temperature of at least 200°F. These ratings are available in manufacturers product literature and refer to UL 2043 ("Fire Test for Heat and Visible Smoke Release for Discrete Products and Their Accessories Installed in Air-Handling Spaces") and other UL and ASTM ratings.
    3. Industry installation recommendations (e.g., ADC (2003)) must be followed.
- A new test method for determining the durability of clamping systems should be developed in order to test the actual failure modes found in the field. Such a test could be incorporated in the UL testing or be a separate ASTM (or equivalent ANSI) test method.
- Until such time as any necessary testing or certification can be implemented, cloth-backed rubber adhesive tapes should not be used unless all the following conditions are met: 1) the joint is round-to-round, core-to-collar; 2) metal or high-temperature plastic strapping is used

The benefits to California from the work in this study are:

- Retention of existing code language that restricts the use of typical duct tapes in certain applications.
- Development and approval of an ASTM standard that the Commission (and other building code authorities) can use to ensure the durability of duct sealants in California buildings.
- Development of improved duct sealants that can be used in California buildings.
- Increased awareness of duct sealing issues by the California building industry.

[2] 60 days is the time period used in other duct sealant tests, such as UL181B.

Abstract

Duct leakage is a major source of energy loss in residential buildings. Most duct leakage occurs at the connections to registers, plenums, or branches in the duct system. At each of these connections, a method of sealing the duct system is required. Typical sealing methods include tapes or mastics applied around the joints in the system. Field examinations of duct systems have shown that taped seals tend to fail over extended periods of time. The Lawrence Berkeley National Laboratory (LBNL) has been testing sealant durability for several years using accelerated test methods and found that typical duct tape (i.e., cloth-backed tapes with natural rubber adhesives) fails more rapidly than other duct sealants. This report summarizes the results of duct sealant durability testing over two years for four UL 181B-FX listed duct tapes (two cloth tapes, a foil tape and an Oriented Polypropylene (OPP) tape). One of the cloth tapes was specifically developed in collaboration with a tape manufacturer to perform better in our durability testing. The tests involved the aging of common "core-to-collar joints" of flexible duct to sheet metal collars. Periodic air leakage tests and visual inspection were used to document changes in sealant performance. After two years of testing, the flex-to-collar connections showed little change in air leakage, but substantial visual degradation from some products. A surprising experimental result was failure of most of the clamps used to mechanically fasten the connections. This indicates that the durability of clamps also need to be addressed ensure longevity of the duct connection. An accelerated test method developed during this study has been used as the basis for an ASTM standard (E2342-03).

Keywords: ducts, air leakage, duct tape, durability, longevity, UL 181 B

Introduction

Background

Air leakage in ducts has been identified as a major source of energy loss in residential buildings. Thirty to forty percent of air flow leaks in and out of ducting systems in residential buildings, and most of the duct leakage occurs at the connections to registers, plenums or branches in the air distribution system (Walker and Sherman 2000). This study is a continuation of previous studies conducted at LBNL (Walker et al. 1998, Walker and Sherman 1998, Walker and Sherman 2000, Sherman et al. 2000, and Sherman and Walker 2003), with the objective of developing new test methods for duct sealant durability, evaluating different sealant types (e.g., tape, mastic, aerosol), facilitating the development of consensus standards (e.g., ASTM), and promoting technology transfer to improve industry practice.

Underwriters Laboratory (UL) have developed safety 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 (UL 1993 and 2003). The current UL 181B standard deals with field assembled flexible duct systems. UL 181B is of a special importance to residential buildings since residential duct systems in the U.S. are normally field assembled. The standard covers pressure sensitive tapes, mastics and (in the latest 2003 version) fasteners[3]. The UL 181B standard only applies to tapes to be used on flex duct core-to-collar connections in conjunction with a mechanical clamp. Six tests are prescribed for pressure sensitive tape: tensile strength,

[3] The terms 'fastener", "clamp", "strap", "drawband", "strapping system" and "clamping system" are all used to described mechanical fastening of flex-duct material to the metal collar. Different references and standards use these terms and we do not make any distinctions between them in this report.

peel adhesion at 180° angle, shear adhesion, surface burning, mold growth and humidity, and temperature tests. However, the standard has very limited tests of the durability of duct sealants. For example, the "shear adhesion test" requires duct tape to sustain specified load without evidence of separation or slippage in excess of 1/8 in (3.2 mm) for only 24 hours. While the UL tests address some important aspects of sealant performance, they do not adequately address durability issues.

The Air Diffusion Council (ADC 2003) 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.

UL 181B and the ADC do not address the collar-to-plenum joint. Instead, they focus only on the core-to-collar joint. Empirically, however, it is observed that the collar-to-plenum joint is a more significant source of air leakage. It is also quite 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 purpose of the current study is to perform accelerated aging tests of UL 181B-FX listed products to evaluate their longevity performance. The products were continuously exposed to high temperature and a typical residential duct system pressure difference for two years. The two year time period was chosen (after consultation with manufacturers of sealant products) to be equivalent to up to 30 years of in-service life assuming that the products were installed in pristine, laboratory conditions with no mechanical stress on the connection. This core-to-collar connection was chosen in consultation with the Energy Commission and sealant manufacturers and was not the same as the collar-to-plenum connection specified in the ASTM E2342-03 standard which was not complete when this study was started. Testing of the core-to-collar connection minimized mechanical stress, but in a real application there will be stress including vibration or shear that might cause failure. Also, if ducts are not fully supported (e.g., when straps fail), the connection is likely to be under mechanical stress. For this reason test methods that include mechanical stress as part of the test will provide superior predictive power in determining sealant longevity. ASTM E2342-03 tests tapes in a condition that puts mechanical stress on the seal by using them in a collar-to-plenum configuration.

Project Approach

The core-to-collar duct connection consisted of a six inch diameter (150 mm) round collar to flex duct core (an example is shown in Figure 1). Four different UL 181-listed duct tape products were used generically called in this report as Tape 1, Tape 2, Tape 3, and Tape 4. Tapes 1 and 2 are conventional duct tapes. Tape 3 is an OPP, acrylic adhesive tape. Tape 4 is a foil-backed, butyl adhesive tape. A nylon strap was used to mechanically hold the connection together for 10 of the 18 samples. The tapes were applied using different combinations of the number of wraps and multiple pieces of tape. Table 1 summarizes the different combinations of tape type, clamping, and wrapping that were tested.

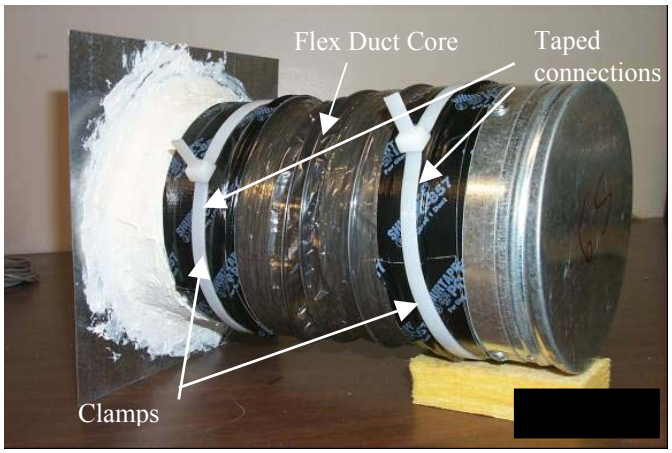

Figure 1. Example of a core-to-collar test sample showing the two taped connections and the mechanical clamps.

Table 1. Aging Test: Summary of core-to-collar combinations after two years of testing

Tape #	Type	Specimen #	Clamping	# of Tape Wraps	Continuous Wrapping
Tape 1	Duct Tape	S7001	√	2	√
		S7002	√	2	
		S7003	√	1	√
		S7004	√	1	
		S7005		2	√
		S7006		2	
		S7007		1	√
		S7008		1	
Tape 2	Duct Tape	S7009	√	2	√
		S7010	√	2	
		S7011		2	√
		S7012		1	
Tape 3	OPP Tape	S7013	√	2	√
		S7014	√	1	√
		S7015		2	
Tape 4	Foil-Butyl Tape	S7016	√	2	√
		S7017	√	1	
		S7018		1	√

Figure 2 shows samples mounted on the aging test apparatus. Heated air is continuously circulated through the test apparatus to both heat and pressurize the leakage sites. The apparatus is divided into an upper and lower chamber that each contains nine samples. The inside of the test samples are exposed to high pressurize (0.34 inch water (84 Pa)) heated air and the outside (shown in Figure 3) is in an insulated chamber that also becomes heated

during the experiments by conduction through the test samples. This means that there is little temperature gradient across the samples. The hot air temperature(200 °F (93 °C)) is controlled using electric resistance heaters mounted directly in the air stream. The surface temperatures of each sample, the air temperature and the pressure across the leaks are continuously monitored using a computer based data acquisition system.



Figure 2. One chamber of the high temperature aging test apparatus.

The air leakage measurements were conducted periodically (typically on a monthly or weekly basis) by removing the samples from the test apparatus. They were then placed in a separate leakage testing device (Figure 4) that pressurized the samples to 0.1 in. water (25 Pa) and measured the airflow rate required to maintain the 0.1 in. water (25 Pa) pressure difference. 0.1 in. water (25 Pa) was chosen because this pressure difference is used as a reference pressure in field testing of duct system leakage[4] and it is typical of average pressures across residential duct leaks.

This 0.1 in. water (25 Pa) airflow rate was also measured before any sealant was applied and after initial sealing. The air leakage after initial sealing was usually very small (about 0.5% of the unsealed air leakage) and accounted for the remaining leakage in the leakage test device and test sample. The difference between the air leakage before and after sealing is therefore the amount of sample leakage that has been sealed by application of the sealant. We set a failure criterion for air leakage at 10% of this difference based on what we considered to be a realistic level of leakage for an individual joint in a real system, and as a leakage level after which samples tended to fail rapidly in our testing.

Previous Project Publications

- LBNL published ASTM Review drafts of sealant durability (and duct leakage) test methods.

[4] Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization (ASTM E1554) and Method of Test for Determining Design and Seasonal Efficiencies for Residential Thermal Distribution Systems (ASHRAE Standard 152)

- LBNL presented a technical paper at an ASTM Sealant Symposium on durability of building sealants in Orlando, FL, January 2003: Walker, I.S. and Sherman, M.H., (2003), Sealant Longevity for Residential Ducts, Durability of Building and Construction Sealants and Adhesives, ASTM STP 1453, A. Wolf Ed., American Society for Testing and Materials, West Conshohocken, Pa. LBNL 50189. http://epb.lbl.gov/Publications/lbnl-50189.pdf

- LBNL completed an interim final report "Advanced Duct Sealing" (LBNL 53547) in September 2003. http://epb.lbl.gov/Publications/lbnl-53547.pdf

- LBNL gave a presentation titled "A Sticky Situation: Durability of Duct Sealants" at the PIER Research Results Seminar at the ASHRAE meeting in Anaheim, January 2004.

Project Outcomes

The testing took place over a total of 773 days. A combination of equipment maintenance and periodic leak testing, visually inspection and photography reduced the total number of days on the test apparatus to 695. The leakage results are shown in Figures 3 through 6. The flexible duct core-to-collar specimens showed no systematic increases in leakage and no catastrophic failures. Most of the samples showed small changes in leakage (either increases or decreases) of 0.2 cfm (at 25 Pa) or less. The exception was one of the foil tape samples, which showed an increase of 0.4 cfm after the first month of testing. However, this sample then stabilized at this leakage level and did not show any significant further leakage increases. Many of the samples showed leakage reductions and our visual observations indicate 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. Several of the samples (10, 11, 16, 17, and 18) showed oozing of the adhesive where it ran out from the confines of the tape and was visually observed on the duct collar surfaces.

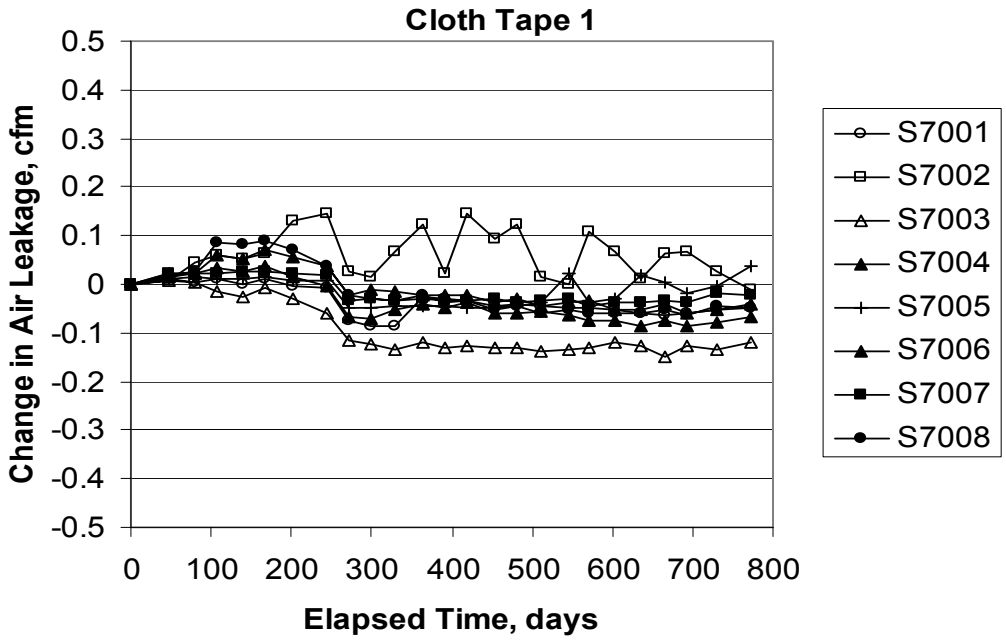

Figure 3. Change in leakage flow of the flexible core to sheet metal collar joint specimens with cloth tape 1.

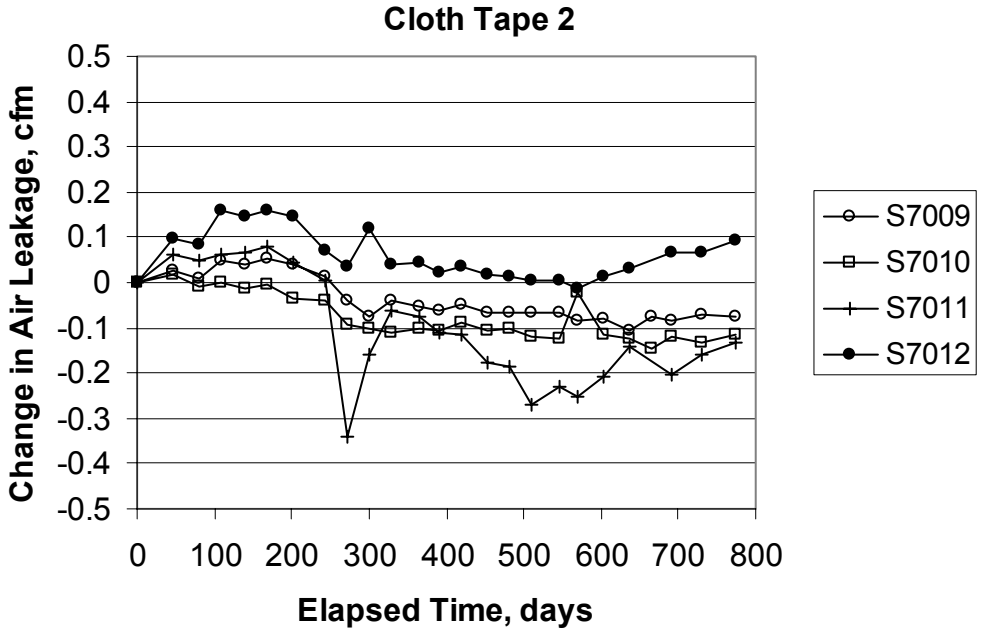

Figure 4. Change in leakage flow of the flexible core to sheet metal collar joint specimens with cloth tape 2.

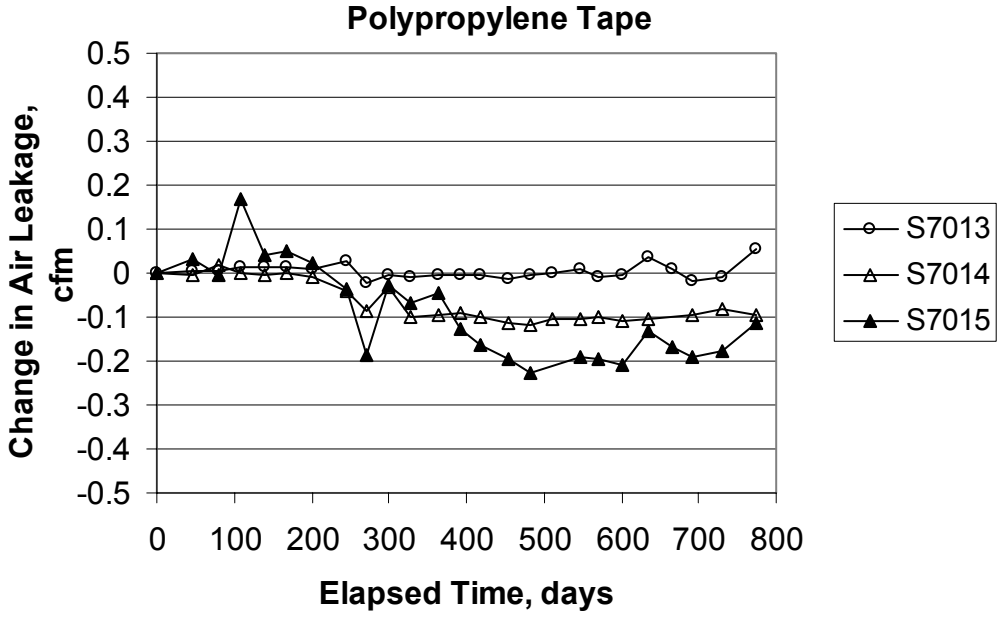

Figure 5. Change in leakage flow of the flexible core to sheet metal collar joint specimens with polypropylene tape 3.

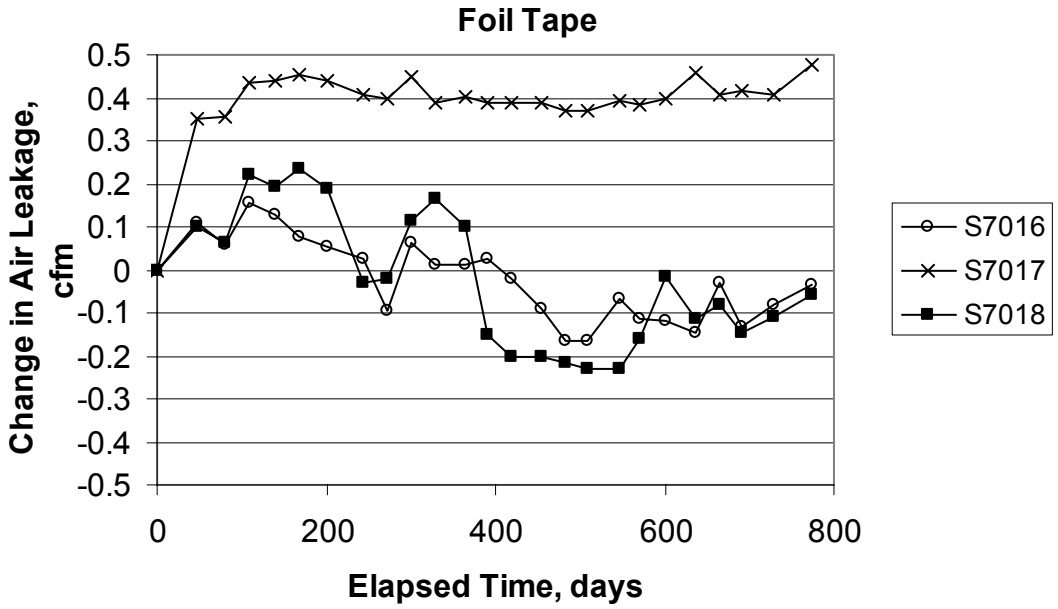

Figure 6. Change in leakage flow of the flexible core to sheet metal collar joint specimens with foil tape 4.

In order to systematically record the visual deterioration of the samples, monthly pictures of all 18 specimens were taken. Typical minor deteriorations were observed as discoloration, wrinkling, and oozing, and major deteriorations were shrinking, peeling, delamination, and cracking. The observations as a result of the visual inspection are summarized in Table 2. Table 2 assigns points (0 to 2) to each of the ten categories of the degradation; "0" denoting either "no sign of deterioration" in that category, "1" denoting a "moderate deterioration", and "2" denoting an "excessive deterioration". Like the visual inspections of the UL 181B test, these points are subjective, but they do serve to give a relative rating for each tape. The table also includes the total number of points given to each specimen. The results show that specimens S7013, S7014, and S7015 (all Tape 3, polypropylene tape) showed the most deterioration, while specimen S7009 (Tape 2, duct tape with clamping, two continuous wraps), and specimens S7017 (Tape 4, foil-butyl tape, with clamping, and one discontinuous wrap), and S7018 (Tape 4, foil-butyl tape, without clamping, and one continuous wrap) showed the least deterioration. Appendix A contains photographs illustrating the deterioration of the samples. Appendix B shows photographs of each sample before testing and at the end of the experiment.

Table 2. Summary of the Visual Inspection Results of the Flexible Duct Core-to-Sheet Metal Collar Specimens in the Aging Test[5]											
Specimen	Hardening and Brittleness	Peeling	Shrinkage	Wrinkling	Delamination	Flaking	Cracking	Bubbling	Oozing	Discoloration	Total Score
S7001	1	1	1	2	0	0	0	0	0	1	6
S7002	1	1	1	2	0	0	0	0	0	1	6
S7003	2	1	1	2	0	0	0	0	0	1	7
S7004	2	1	1	2	0	0	0	0	0	1	7
S7005	2	0	1	2	2	0	0	0	0	1	8
S7006	2	1	2	2	2	0	0	0	0	1	10
S7007	2	1	2	2	2	0	0	0	0	1	10
S7008	2	1	2	2	2	0	0	0	0	1	10
S7009	2	0	0	1	0	0	0	0	0	0	3
S7010	2	0	0	1	0	0	0	0	1	0	4
S7011	2	0	0	2	0	0	0	0	1	0	5
S7012	2	0	0	2	0	0	0	0	0	1	5
S7013	2	2	0	2	2	2	2	2	0	2	16
S7014	2	2	0	2	2	2	2	2	0	2	16
S7015	2	2	0	2	2	2	2	2	0	2	16
S7016	0	0	0	2	0	0	0	0	2	0	4
S7017	0	0	0	1	0	0	0	0	2	0	3
S7018	0	0	0	1	0	0	0	0	2	0	3

[5] "0" denotes "no sign of deterioration", "1" denotes "moderate deterioration", and "2" denotes "excessive deterioration"

Strap failure

One unexpected result of the core-to-collar testing was the failure of the nylon straps. The discoloration of the nylon strapping observed within one month of the start of testing was an indication of thermal deterioration that later lead to total failure. Two different nylon strap materials were used and both showed the same brittle failure. The two strap types were identified by their color: beige and gray. The beige straps turned ochre with age and the gray straps turned a darker green/gray color. The nylon straps all showed the same failure mechanism due to the increased brittleness of the plastic. The failure point for most of the straps was at the point of greatest stress: where the strap passes through the ratchet. Two straps were used on each strapped sample – one at the cap end and one at the flange end. Several of the samples had their end cap and flange straps fail at different times and the failure times for each end were recorded separately. Table 3 summarizes the times of strap failure on the ten samples that used clamps.

One sample (S7014) had strap failure after four months of aging (Figure 7). Other straps lasted longer, however, all but two failed by the end of testing. The two remaining straps show the same discoloration as failed straps – but have not completely fallen off. The results show no significant pattern for flange or end caps failing first, the two straps on each sample generally failed within a couple of months of each other. Strap failure potentially is a major problem because mechanical attachment thereafter only is maintained by the duct sealant. If ducts are not well-supported, significant mechanical stress can occur to cause the sealant to fail after the clamp fails.



Figure 7. Failed plastic strapping on one of the flexible core to sheet metal collar specimens after four months of aging.

Testing of the straps had not been considered part of the original experiment, so little variability in strapping materials was selected. 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 (e.g. Heat Stabilized Nylon 6/6 for continuous exposure above 185 °F and TEFZEL for

even higher temperatures) and may have improved high-temperature durability. As an alternative, metal straps are unlikely to fail at even higher temperature ranges.

Table 3. Failure of nylon straps					
Beige Straps			**Grey Straps**		
	Days to failure			**Days to failure**	
Sample Number	**Cap**	**Flange**	**Sample Number**	**Sample Number**	**Cap**
7001	**359**	**119**	**7013**	**7001**	**359**
7002	**401**	**359**	**7014**	**7002**	**401**
7003	**552**	**756**	**7016**	**7003**	**552**
7004	**359**	**756**	**7017**	**7004**	**359**
7009	**INTACT**	**674**		**7009**	**INTACT**
7010	**756**	**INTACT**		**7010**	**756**

UL181B Revisions for Straps

In 2003 UL181B was revised to include a new test for fasteners including straps. Products that pass the test are to be marked UL 181B-C. 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 this study 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 straps are not tested at high temperature, instead they are conditioned for 48 hours at 23°C (and 50% RH) before testing at some unspecified temperature. In other words the strength at high temperature is not evaluated, instead the effect of high temperature exposure on material properties is the object of the test. Because our testing started before this new UL clamp requirement we were not able to evaluate the performance of UL listed clamps. However, this testing should be carried out in the future, particularly in light of the clamp failures we experienced and the failure of tape products in baking tests (in Sherman and Walker 2003) that were UL listed.

While a good step forward, the new UL test falls short in being a good indicator of strap performance. The problems with the UL test are:

- The straps are not tested in the failure mode that we observed in our testing, i.e., brittle failure in bending. Many of our observed failures were where the tie passes through the ratchet mechanism and has to bend through 90 degrees. We do not know if the strapping materials show greater or lower tensile strength as they become more brittle; many ductile materials in fact 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 our 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 so.

- The testing is for 60 days only. In the current study, none of the straps failed in 60 days. Testing for only 60 days appears to be sufficient.

- The test wording is unclear: "Three fasteners are to be fastened around a 4 inch galvanized sleeve (mandrel) with a diameter of 4 inches (102 mm). The samples are to be installed in the intended manner and installation tools (if provided) are to be used according to the manufacturer's instructions. The average peak tensile strength of the three samples shall not be less than 100 lb (45.5 kg). The peak tensile strength value for an individual sample shall not be less than 90 lbs (40.8 kg)." If the samples are installed around the sleeve – how is their tensile strength tested? If all three are tested at once, how can one evaluate the minimum strength of an individual fastener?

Developing a standardized test method for evaluating duct sealant durability

The ASTM test procedure evaluates sealants using a collar-to-plenum connection as used in previous studies and for the advanced sealant testing in this study. Use of this connection places a mechanical stress on the tape sealants because they must conform to the shape of the joint and provides for measurable air leakage that can be used as an objective basis for determining sealant failure (unlike subjective visual inspection tests).

Development of the ASTM standard continued during the current study, including changes to the test procedures to use heating only (earlier drafts had both heating and cooling of samples), and an increase in test temperatures. The change to heating only was made in order to make the testing simpler because cooling added significant cost and complexity to the testing. The increase in temperatures was to bring the durability testing more in-line with the existing UL181B-FX temperature test and comments received on the previous draft from ASTM ballots. Administrative tasks included preparation of drafts, preparation of supporting materials for ASTM ballots, preparing responses to comments received from the ASTM ballot process, and interactions with ASTM staff and other task group members. The ASTM Standard has completed the ASTM approval process and is now available as ASTM E2342-03 "Standard Test Method for Longevity Testing of Duct Sealant Methods."

Although few sealants have formally been tested with E2342-03, we would expect that E2342 results would track our previously reported test results because of the similarity in methods. The relevant result of our previous work is that cloth-backed, rubber adhesive tapes demonstrated significantly lower longevity than other sealants.

Conclusions and Recommendations

The core-to-collar connections had no significant failures in terms of leakage over two years of testing, but some samples showed significant visual degradation. Many of the joints became brittle during the test, which would imply that mechanical stress in almost any form could cause them to fail. Testing of the core-to-collar connection minimized mechanical stress, but in a real application there will be stress including vibration or shear that might cause failure. Also, if ducts are not fully supported (e.g., when straps fail), the connection is likely to be under mechanical stress.

For this reason test methods that include mechanical stress as part of the test will provide superior predictive power in determining sealant longevity. Both our previous test method and ASTM E2342-03 tests tapes in a condition that puts mechanical stress on the seal—by using them in a collar-to-plenum configuration. Furthermore the ASTM standard is a consensus standard that has passed the rigorous reviews required by ANSI. Thus ASTM E2342-03 is preferred over the core-to-collar testing presented in this report because it is likely to be more indicative of duct sealant performance in the field and will better safeguard California duct systems against failure in applications and conditions that are likely to occur in the field.

Another key result was that almost all the clamps used in our testing failed during the two years of testing. They all failed in the same way – becoming discolored and brittle and finally falling off the samples. For this reason we recommend either requiring metal clamps or other high temperature materials. Given that clamps are required as part of a UL181B-FX sealing system, this failure of clamps is a very important issue. It should be noted that a recent revision of UL181B includes a 60 day high temperature test for clamps, but it is not clear that this test evaluates the clamps in the failure mode that we observed. The visual degradation combined with the failure of the straps means that the tested joints failed, despite the fact that there was no appreciable increase in air leakage. The significance of this failure cannot be directly inferred from our experiments because best efforts were made to minimize mechanical stresses in the tested joints. Field observation has shown that joints often have significant mechanical stresses applied to them during construction, operation, maintenance and renovation. Failed clamps will lead to mechanical stress common in the field directly acting to reduce the longevity of the duct sealant.

The benefits to California of the work in this study are:

- Retention of existing code language that restricts the use of typical duct tapes in certain applications.
- Development and approval of an ASTM standard that the Commission (and other building code authorities) can use to ensure the durability of duct sealants in California buildings.
- Development of improved duct sealants that can be used in California buildings.
- Increased awareness of duct sealing issues by the California building industry.

Implications for Title 24, Part 6

Since the 2001 Building Energy Efficiency Standards were passed California requires that "*Joints and seams of duct systems and their components shall not be sealed with cloth back rubber adhesive duct tapes unless such tape is used in combination with mastic and drawbands*."

The industry objected to this requirement and the commission opened a rulemaking, Docket 02-BSTD-1, to consider possible revisions to the Standards related to the issue. Potential revisions would have allowed cloth-back, rubber adhesive tapes to be used on core-to-collar connections only, which meet the installation recommendations of the ADC. As a result of that rulemaking the Commission decided not to adopt any changes to the Standards (see attached Notice of Committee Conclusions at:
http://www.energy.ca.gov/title24/ducttape/notices/2002-03-26_COM_CONCLUSIONS.PDF

The results of this report support the Commission's decision.

Now that longevity can be evaluated using ASTM E2342-03, the current Title 24, Part 6 provisions for cloth back rubber adhesive tapes should be replaced in future versions of the Standards by a longevity requirement. Because ASTM E2342-03 creates a performance metric, we do not see the need for future versions of the Standards to call out specific classes of products as it currently does for cloth-backed rubber adhesive tapes.

We recommend that:

- At the next appropriate standards revision cycle the following changes should be considered:
    1. The special provisions for cloth back rubber adhesive tapes in Title 24 should be removed and replaced by a requirement that all sealants pass an ASTM E2342 test for a test period of at least 60 days[6].
    2. Straps must be rated for continuous use at a temperature of at least 200°F. These ratings are available in manufacturers product literature and refer to UL 2043 ("Fire Test for Heat and Visible Smoke Release for Discrete Products and Their Accessories Installed in Air-Handling Spaces") and other UL and ASTM ratings.
    3. Industry installation recommendations (e.g., ADC (2003)) are followed.
- A new test method for determining the durability of clamping systems should be developed in order to test the actual failure modes found in the field. Such a test could be incorporated in the UL testing or be a separate ASTM (or equivalent ANSI) test method.
- Until such time as any necessary testing or certification can be implemented, cloth-backed rubber adhesive tapes should not be used unless all the following conditions are met: 1) the joint is a round-to-round, core-to-collar one; 2) metal or high-temperature plastic strapping is used.

[6] 60 days is the time period used in other duct sealant tests, such as UL181B.

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ASHRAE Standard 152P, (2003) "Method of test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems". ASHRAE, Atlanta, GA.

ASTM Standard E2342-03 (2003) "Standard Test Method for Longevity Testing of Duct Sealant Methods". American Society for Testing and Materials, West Conshohocken, PA.

ASTM Standard E1554-03 (2003) "Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization", American Society for Testing and Materials, West Conshohocken, PA.

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Underwriters Laboratory (UL). (2003). Standard for Closure Systems for Use with Flexible Air Ducts and Air Connectors – UL 181B. Underwriters Laboratories Inc. Northbrook, IL.

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Example sources for high temperature cable-tie/clamp information:

http://www.nelcoproducts.com/ties/ct_material_spec.cfm

http://www.planetcableties.com/download_catalog.shtml

Appendix A. Examples of visual deterioration

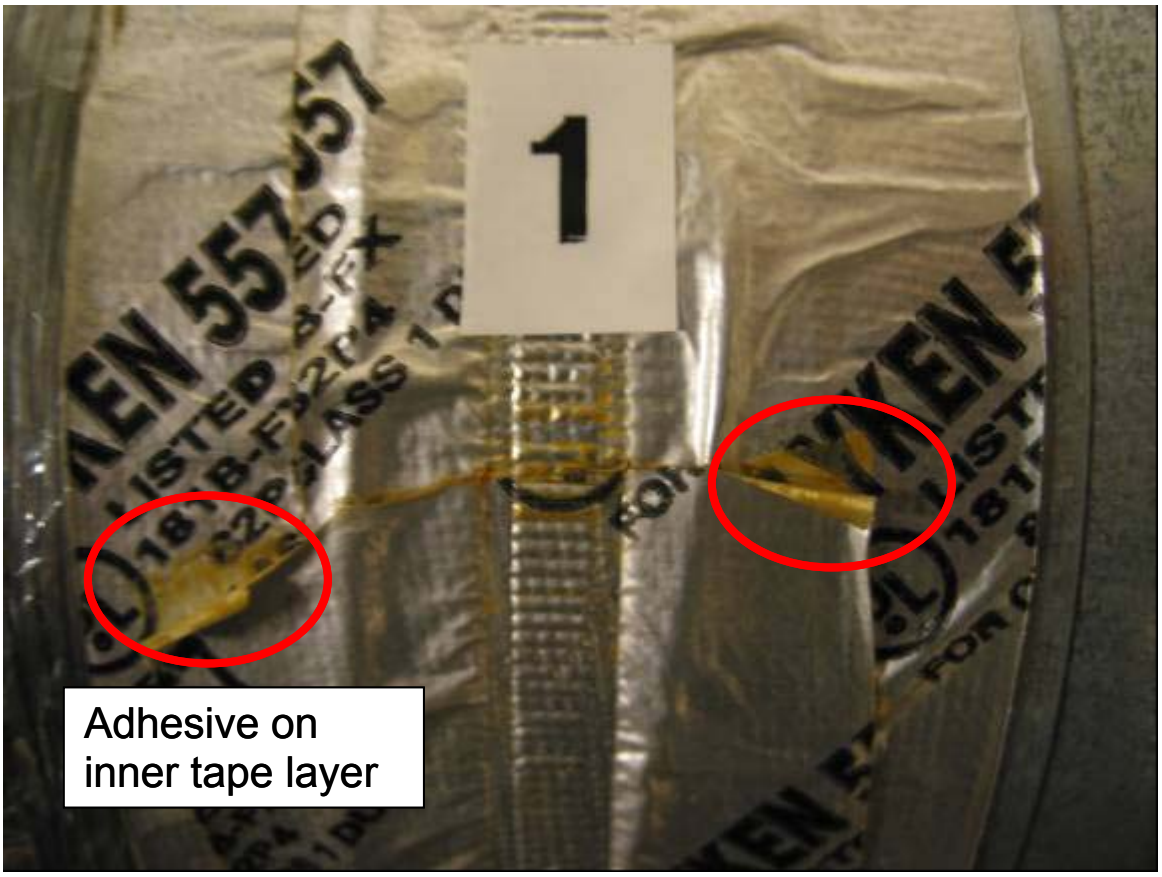

Figure A1. Sample 1. This figure shows the curling of the tape end where it is no longer stuck to the inner layer of tape. The yellow (circled) areas show where the adhesive has remained on the inner tape layer. The tape edges have curled away from the duct and the tape surface is wrinkled. The indentations in the center of the tape shows where the strap used to be before it fell off.



Figure A2. Sample 1. The second seal still has part of the nylon clamp in place. This shows the same characteristics as in Figure A1.

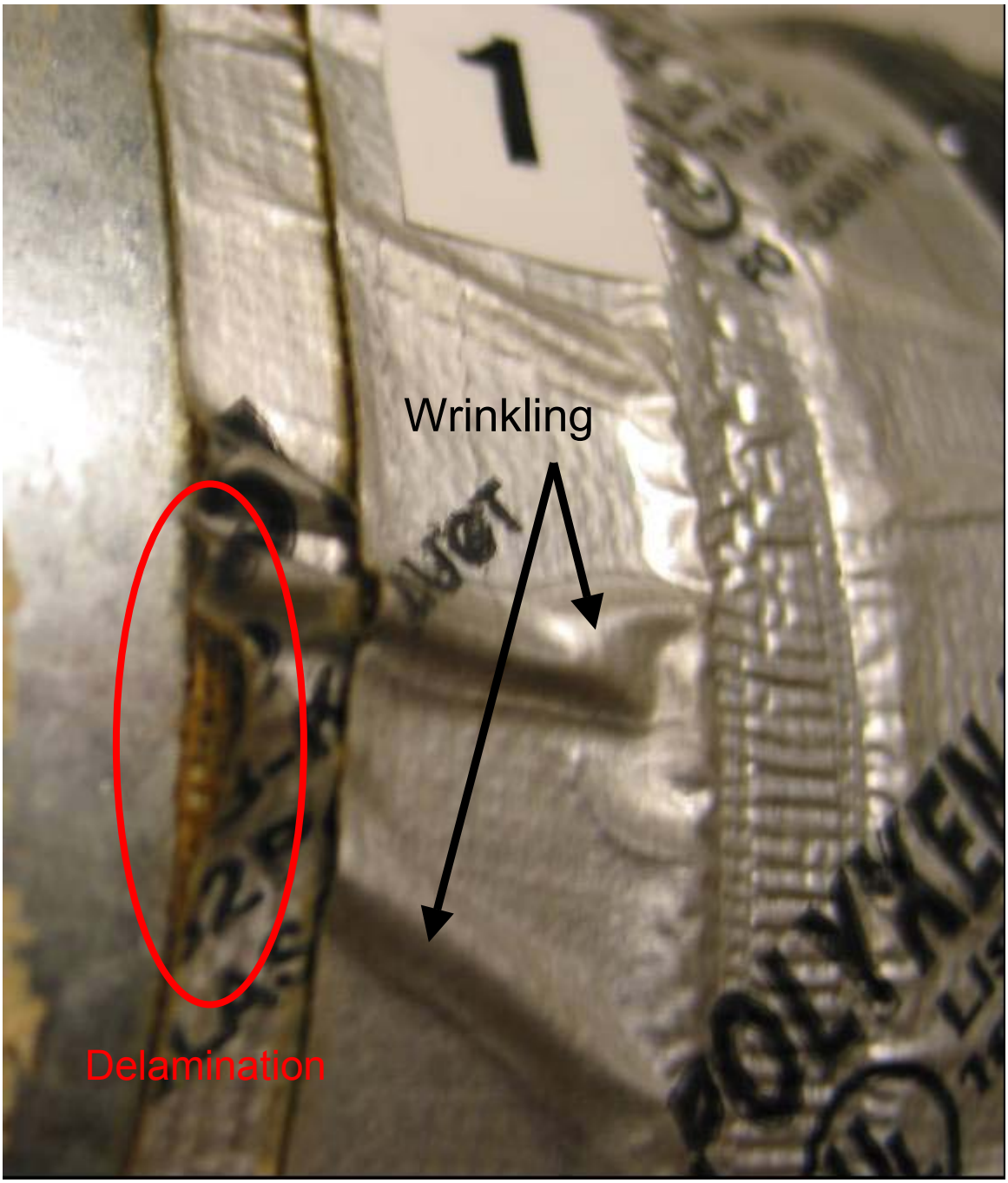

Figure A3. Sample 1. The tape shows wrinkling and delamination of the reinforcing mesh from the tape backing.



Figure A4. Sample 3. Tape has separated from the flex duct core at the tape edges

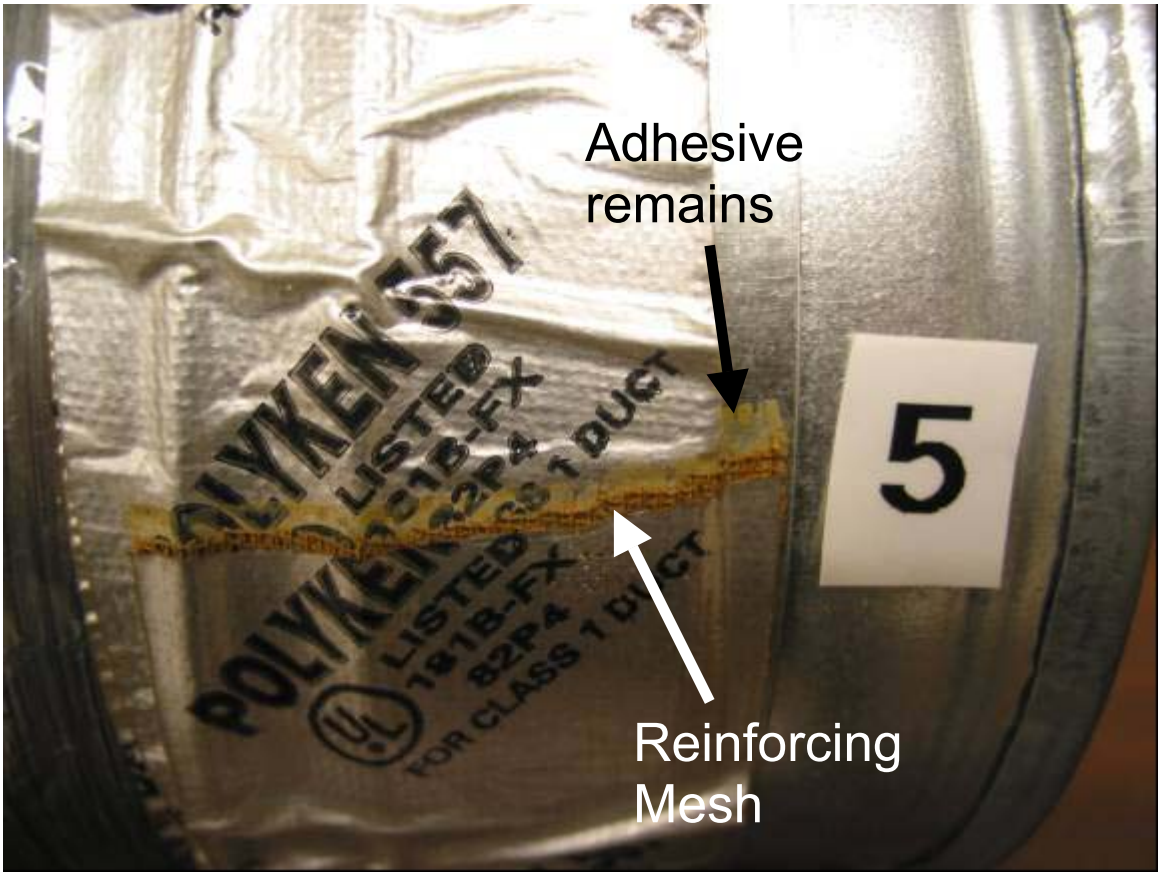

Figure A5. Sample 5. The end of the tape shows shrinkage and delamination. Compare this to Figure A1, where the presence of the clamp in A1 reduces the shrinkage and delamination at the center of the tape. This figure clearly shows the adhesive left where the tape was originally attached and the reinforcing mesh separated from the backing.

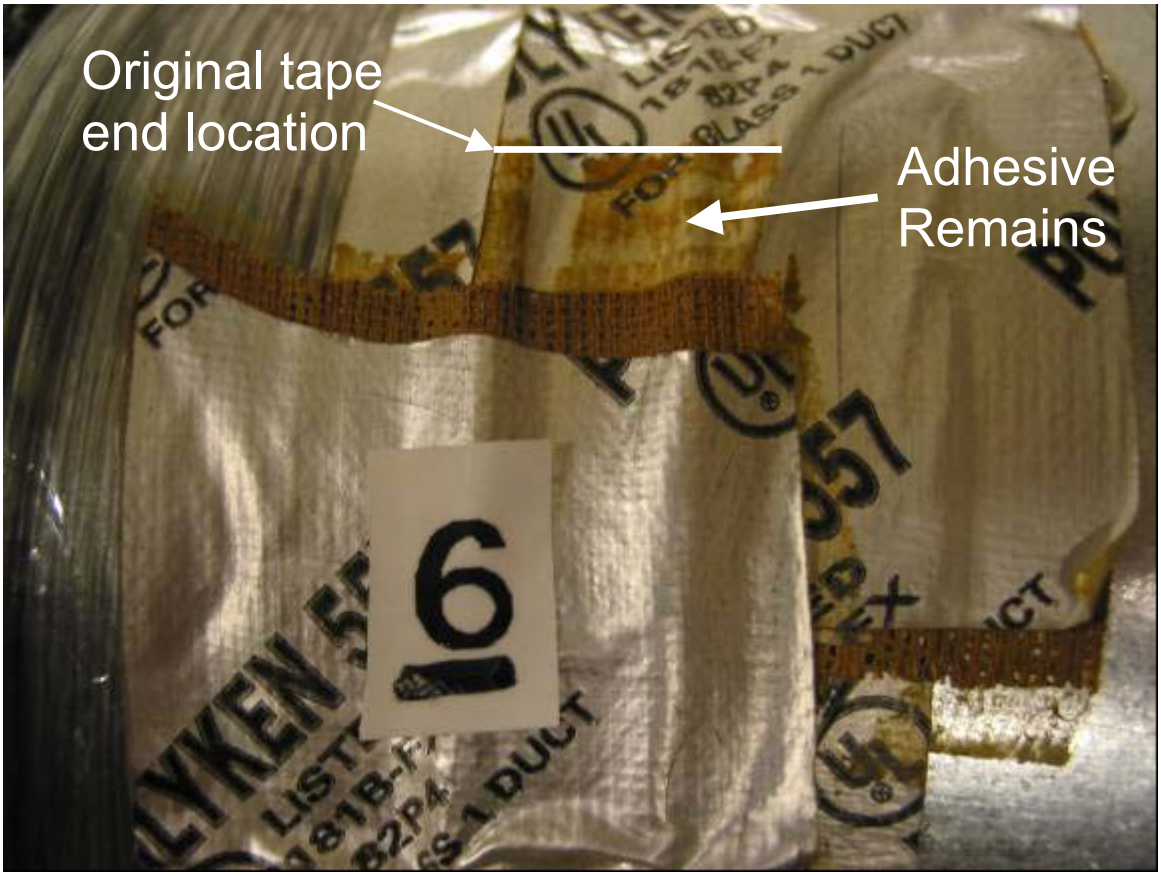

Figure A6. Sample 6. This figure is similar to Figure A5, but shows even more shrinkage.



Figure A7. Sample 7. Like sample 6, sample 7 shows considerable shrinkage and delamination.



Figure A8. Sample 7. The edges of the tape have lifted off the duct surface in large wrinkles.



Figure A9. Sample 8. The edges of the tape are no longer stuck to the flex duct core.



Figure A10. Sample 9. The clamp shows its brittle failure. Note that these clamp sections are now held in place because they are stuck to the duct tape.



Figure A11. Sample 9. This sample shows almost no shrinkage or delamaination.



Figure A12. Sample 10. The adhesive has oozed out onto the surface of the duct.



Figure A13. Sample 11. The adhesive has oozed out the edge of the tape.



Figure A14. Sample 12. The end of the tape has wrinkled and shrunk.



Figure A15. Sample 13. This sample shows cracking and disintegration of the tape



Figure A16. Sample 13. This sample is cracking and peeling.



Figure A17. Sample 14. This sample shows the same cracking and splitting as Sample 13.



Figure A18. Sample 15. Like samples 13 and 14, this sample is also peeling and cracking. This figure shows how the metallized layer is splitting from the adhesive layer.



Figure A19. Sample 16. This sample shows oozing of the adhesive at the tape edges.



Figure A20. Sample 17. As with sample 16, this metal foil tape is showing oozing of the adhesive. Note that there is no shrinkage or delamination like the other tapes at the end of the tape. There is also a small piece of clamp stuck in place by the oozed adhesive.

Appendix B. Initial and Final photographs of test samples





Sample 1





Sample 2





Sample 3



Sample 4





Sample 5





Sample 6





Sample 7





Sample 8





Sample 9





Sample 10





Sample 11





Sample 12





Sample 13





Sample 14





Sample 15





Sample 16





Sample 17





Sample 18



Appendix C: Notice of Committee Conclusions

DUCT TAPE RULEMAKING PROCEEDING
Docket 02-BSTD-1
March 26, 2002

BACKGROUND

In response to a petition filed by Tyco Adhesives and Shurtape Technologies, Inc. (Tyco), the Commission opened a rulemaking proceeding to consider possible repeal or amendment of requirements in the California Code of Regulations, Title 24, Part 6 (Building Energy Efficiency Standards) that allow the use of cloth back rubber adhesive duct tape for sealing ducts only if installed in combination with mastic. The current requirements were adopted by emergency pursuant to AB 970 in January, 2001. The regulations were subsequently readopted and made permanent in April, 2001. They went into effect for nonresidential buildings and some residences on June 1, 2001. They went into effect for the remaining residential buildings on January 1, 2002. In granting the petition, the Commission took no position on the substantive merits of Tyco's petition.

Since the mid-1990s the Commission has recognized the severe energy and peak demand problems caused by badly designed, sealed and installed heating, ventilation and air conditioning (HVAC) system ducts. In 1998 the Commission took a first step to address these problems in its performance standards by giving compliance credit for duct efficiency improvement, in particular for pressure-tested and field verified ducts that are sealed using long-lasting sealant products.

In 2000 the Legislature enacted AB 970, requiring the Commission to adopt new measures in the building energy efficiency standards to reduce peak electric load to respond to the State's electricity crisis. The Commission adopted several new requirements, among them are requirements that do not allow cloth-back rubber adhesive duct tape for the connecting of joints in HVAC system ducts unless such tape is used in combination with mastic. These are the requirements that Tyco has petitioned to repeal or amend, so that cloth back rubber adhesive duct tape alone can be used on duct joints, without the use of mastic

EXPRESS TERMS AND COMMITTEE HEARING

On February 22, 2002 the Commission opened a rulemaking proceeding to consider possible repeal or amendment of the requirements for cloth back rubber adhesive duct tape. To start the rulemaking the Commission released for consideration Express Terms (45 Day Language) to respond to concerns expressed by Tyco. The Express Terms would amend the requirements to allow the use of cloth back rubber adhesive duct tape without mastic for a limited time (until January 1, 2004) on only those duct connections where manufacturers recommend (on flex duct to fitting joints) in strict compliance with specific installation procedures. This allowance would only apply to field-fabricated duct systems in low-rise residential buildings.

The Commission stated the following in its Initial Statement of Reasons:

The Express Terms result from a specific proposal in a petition for rulemaking. One alternative is to not adopt the Express Terms. Other alternatives to the Express Terms may be proposed by participants in the rulemaking proceeding. At this point the Commission has not rejected alternatives to the Express Terms.

The Energy Efficiency Committee held a hearing on March 21, 2002 to receive public comment on the Express Terms.

SUMMARY OF KEY COMMENTS

The following is a summary of the key comments that the Committee heard at the March 21, 2002 hearing.

California Building Officials (CALBO) opposes any changes to the Standards at this time. A major effort has been made to get building officials (approximately 550 jurisdictions statewide) and the building industry trained on the new Standards. There is no reason to change. The industry has already moved away from cloth tape or is in the process of doing so. The current options for compliance are fully satisfactory. The duct tape requirements are one

of the easiest aspects of the Standards to enforce. Making a change to the Standards at this time would be very disruptive and would reduce the credibility of the Standards.

California Building Industry Association (CBIA) agrees with CALBO. Making a change to the current duct tape requirements undercuts a CBIA effort that has been going on since 1998 to train the largest California builders in how to do a good job of sealing ducts using long-lasting duct sealing materials. There is no problem with the industry being able to comply with the current Standards. If a more rigorous installation process was required to make it possible to use cloth back rubber adhesive duct tape in limited applications, builders would likely choose to use other sealing alternatives.

Insulation Contractors Association (ICA) supports CALBO's position. Insulation contractors get callbacks from customers not seeing an impact in their energy bills after an insulation upgrade. Often the problem turns out to be bad duct sealing. Bad duct sealing costs insulation contractors money. If the Commission's goal is to get high performance duct tape into the California market, then the way to do that is to keep the Standards the way they are.

Tyco and Shurtape support Commission adoption of the Express Terms. They agree with other stakeholders that the Express Terms should be improved to include other specific installation requirements for cloth back rubber adhesive duct tape. They will put installation instructions in shipping boxes for duct tape, will put an abbreviated set of instructions in the liner of the core of the tape roll, and will put a marking agreed to with the Commission, which says this tape is prohibited from use on other than flex duct to fitting joints, at intervals on the tape backing. They will work with the Commission to train building officials and contractors about installation practices that are acceptable to the Commission. They will work with the Commission and LBNL to develop a new test procedure that will insure that future duct tape products will last for the life of the home, accounting for hot temperatures and dirty conditions in California attics where ducts are installed.

Rottiers Sales Associates (Northern California distributor of Tyco products) are continuing to supply cloth back rubber adhesive duct tape to areas of Northern California outside of the Sacramento area where building officials are not enforcing the 2001 Standards requirement.

Proctor Engineering (California air conditioning systems expert and field researcher) urges the Commission to not allow the use of cloth back rubber adhesive duct tape. Sealing ducts is a very important energy savings and peak demand reduction action. Once construction of a house is finished, the joints where ducts leak are often inaccessible inside walls or under insulation in attics. If the joint fails, it will stay failed for the life of the house, wasting energy and the homeowner's or renter's money the whole time. He presented survey data that shows that a significant portion of contractors fail to follow manufacturer's installation instructions. He believes this can't be changed by a revision to the Standards. Installation instructions similar to the Express Terms currently are included in flex duct shipping boxes, but they don't get followed consistently. If the Commission wants to allow cloth tape, several key points would need to be added to the Express Terms to make the installation instructions acceptable.

Pacific Gas and Electric Company (PG&E) recommends that the Commission not change the Standards. Failed duct sealing means higher energy bills for their customers. Their programs have not allowed cloth tape since 1998. PG&E thinks that the installation instructions that are supplied with flex ducts are a good idea, but since they are printed on a small piece of paper in very small type, they could easily be disregarded by installers. If the Commission wanted to allow cloth tape, several points would need to be added to make the installation instructions in the Express Terms satisfactory. They think that rigorous installation instructions that are rigorously enforced would discourage the use of cloth tape. They agree that the use of cloth tape should be prohibited for collar to plenum joints.

Lawrence Berkeley National Laboratory (LBNL) recommends to not allow the use of cloth tape on collar to plenum joints and not allow the use of cloth tape if industry installation recommendations are not consistently followed. Their past testing shows that cloth back rubber adhesive duct tape is not a long-lasting duct sealing product. They recently have begun additional testing of duct tape on flex duct to collar joints. There are early signs of degradation of a sample, which was not installed to meet manufacturer's installation instructions.

C. A. Shroeder, Inc. (CASCO - factory-fabricated flex duct manufacturer) said that a building official cannot tell whether the flex duct to fitting joint is properly installed because it is covered up by the flex duct liner, which is then sealed. The building official will not take the joint apart to see if was correctly installed.

Underwriters Laboratories (UL) was not aware of a problem with cloth back rubber adhesive duct tape prior to the Commission's actions. UL does not have the resources to keep track of research, such as that in the building science literature over the past several years regarding the failure of duct tape. UL has limited ability to make changes to its requirements on its own authority. UL primarily gets its advice from manufacturers, but it is open to other input so long as it is submitted in a formal way following UL procedures. UL requires flex duct manufacturers to put installation requirements for sealing the flex duct to fitting joint in packing boxes. UL only endorses the use of duct tape on the flex duct to fitting joint when the installation is fully compliant with these instructions. UL has no mechanism to address problems with using duct tape on other duct system joints or failure of installers to follow the installation instructions. UL has not considered the possibility of requiring duct tape to be more durable so as to withstand installation problems that occur in the field.

Intertape Polymer Group (duct tape manufacturer) in a letter submitted to the Commission after the hearing urged the Commission not to adopt changes to the 2001 Standards. The letter stated, "… the CEC would be remiss in allowing duct tape to be continued to be used on an application that would waste energy and millions of dollars paid for that energy … the pressure sensitive tape industry has come up with a solution to this problem, that is the UL 181 B-FX polypropylene backed tape with acrylic adhesive … and the fact that this product already exists in the marketplace [indicates] there is no hardship created by enforcing this change."

COMMITTEE FINDINGS

Based on the comment received at the March 21, 2002 hearing and documents submitted to the docket, the Energy Efficiency Committee finds that adoption of the Express Terms is unnecessary and would be disruptive to the effective implementation of the 2001 Building Energy Efficiency Standards. The Express Terms would fail to insure that sealing duct systems with cloth back rubber adhesive duct tape would result in long-lasting sealing, and would fail to protect California from the potentially major energy and peak demand consequences of inadequately sealed ducts. The Committee believes that only long-lasting duct sealing products, which are resilient to the conditions in which they are installed and installation practices that fail to meet ideal recommendations, should be allowed for use in California. The Committee also is concerned with the admission of a Tyco business associate who knowingly has continued to supply cloth back rubber adhesive duct tape for installations that would not be in compliance with the 2001 Building Energy Efficiency Standards.

COMMITTEE RECOMMENDATION

The Energy Efficiency Committee recommends that the Commission not adopt the Express Terms or any other changes to the Building Energy Efficiency Standards in response to the Tyco petition.

Signed:

ROBERT PERNELL
Commissioner and Presiding Member
Energy Efficiency Committee

ARTHUR H. ROSENFELD
Commissioner and Associate Member
Energy Efficiency Committee