REV 04/12

Steel Plate Expansion Joint Systems

Drainage Trough Splice Vulcanization Methods

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Introduction

Drainage trough splicing consists of joining two pieces of material to form a single, continuous part. Two methods are available to fabricate drainage trough splices: hot vulcanization and cold-chemical vulcanization. Hot vulcanization involves using a press that heats the material and applies pressure to form a vulcanized splice. Cold-chemical vulcanization utilizes a two-part rubber-compatible structural adhesive to form a splice. By means of a battery of splice tests, this study sets out to show the advantages and disadvantages of both systems as applied to drainage trough manufacturing.

Splice testing was completed using ASTM D429 Method B. Although many states choose to specify different elastomers, neoprene was chosen based on its acceptance by the Federal Highway Administration. Six samples of each splice method were tested to provide average test results. The results of each peel test are detailed in the Appendices. The results table shows average values in pounds per inch of width (lbf/in) and maximum load placed on the sample in pounds. The curve shown is a depiction of the force generated on the last peel in each test category.

Hot Vulcanization

Hot vulcanization uses a splice press that applies heat and pressure to two distinct pieces of drainage trough material and an uncured elastomeric interface, thereby crosslinking the remaining cure sites on the drainage trough material with the cure sites in the uncured elastomer to form a single piece of material. The crosslinking agent, typically sulfur, is a difunctional molecule that, through chemical reaction, joins two polymer chains together to create a single chain, thereby forming a single piece of material. Bonds made under heat and pressure are subject to chemisorption, which is characterized by strong covalent bonds between the surfaces being joined.

The mechanics that create crosslinked bonds are heat and pressure. Heat speeds up molecular vibration and helps break sulfur molecules down into smaller chains. These chains then react with cure sites. Pressure is required during drainage trough vulcanization to drive the melt into the substrate and force intimate contact between the surfaces being bonded, thereby helping free sulfur agents crosslink with the bond sites. Pressure also ensures that there are no air gaps in the bond. Crosslinking forms a single, unbroken chemical chain from two or more individual chains, which is to say that two or more individual pieces of material are formed into a single piece. The end result is a strong, continuous piece of material.

Lab testing shows hot vulcanized splices exceeding the most stringent state specification for peel testing by an average of 283% (Iowa Department of Transportation Standard Specification 4195.02, Table B, ASTM D429 Method B of 40 lbf/in). The average peel test value of a D.S. Brown hot vulcanized splice is 153.41 lbf/in (see Appendix A1, peel 25 to peel 30).

Test results show that hot vulcanization has some degree of variability. Peel 26 (97.231 lbf/in) and peel 27 (181.429 lbf/in) show an 87% difference between the minimum and maximum test results. However, this variability is compensated by the minimum test result. Peel 26 (97.231 lbf/in) passed the peel test standard by 143%.

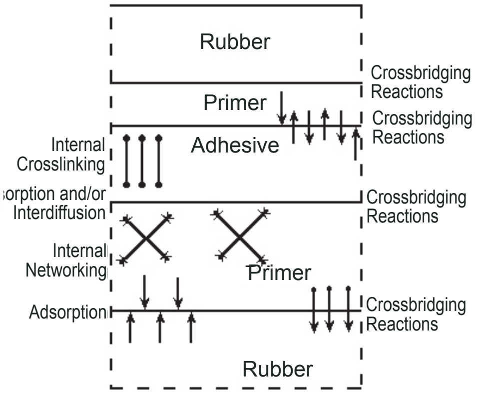
The process of hot vulcanization lends itself to quality and accuracy. After being cut to size and prepared for splicing, press operators have ample time to correctly align splice geometry. There is no rush to complete this important part of the trough manufacturing process. Hot vulcanization is unaffected by ambient conditions because the process does not rely on substrate temperature for curing. The result of this process is a consistent splice and accurate geometry.

Hot vulcanized splices are tested using witness pieces. Witness pieces are vulcanized in process, or in the same heat, with the drainage trough splices they represent. They are then tested to verify bond strength. This eliminates any guesswork in quality control by testing what are, in effect, actual splices.

The mode of hot vulcanized splice failure provides key advantages over other splice methods. In peel testing, the splice itself is not the point of failure; rather, the elastomeric substrate separates from the first layer of reinforcing fabric, thereby moving failure away from the critical splice and into the body of the drainage trough. No tearing occurs at the splice; rather, hot vulcanized splices maintain drainage trough geometry and continue to prevent water leakage.

Cold-Chemical Vulcanization

Cold-chemical vulcanization uses a two-part rubber-compatible structural adhesive system to bond drainage trough material. The structural adhesive system consists of a polymer composed of solids and fillers suspended in solvent, and a hardener. The hardener acts as a catalyst to start internal crosslinking in the adhesive, which cures the mixture. When properly applied, the structural adhesive facilitates bonding by providing a crossbridging agent. A crossbridging agent is a difunctional molecule that, through chemical reaction, joins polymeric materials together that are on opposite sides of an interface. In this case, the interface is the structural adhesive. Although a bond is created and the parts are joined, the two distinct pieces of drainage trough material continue to remain unique, separated by an adhesive interface. Bonds made using structural adhesives are reversible across the adhesive interface plane. The chemical reactions created during cold-chemical vulcanization are shown below.



Anatomy of a Cold-Chemical Bonded Elastomer.

Lab test results show that the average cold-chemical bond passes Iowa's benchmark peel test standard. Cold-chemical bonds show an average peel test value of 41.1 lbf/in, exceeding the requirement by 2.9%. Structural adhesive manufacturer's test results show that cold-chemical bonds may exceed specifications by a maximum of 50%. However, not all tested splices passed the 40 lbf/in requirement. Peels 140 and 142 tested at 36.058 lbf/in and 24.641 lbf/in, respectively (Appendix A3). A difference of 27.352 lbf/in, or 110%, exists between peel 144 (51.993 lbf/in) and peel 142 (24.641 lbf/in). This shows process variability, which ranges from failure at 38.4% below standard to passage at 30% above standard. Further testing has revealed that variability is largely due to ambient conditions at the time of bonding. By taking these conditions into account, a more consistent bond can be created.

There are a number of critical processes that must be controlled during cold-chemical vulcanization. Substrate preparation is the first step when performing cold-chemical vulcanization. The primer must adsorb, or form a thin film of molecules or atoms onto the substrate surface, for bonding to occur correctly. The substrate will not accept the primer unless it is buffed. Buffing removes wax and oil, reduces the wetting angle to allow the primer to properly adsorb, and creates a profile in the substrate resulting in a higher exposed surface area and a higher surface capacity for adsorption. Improper substrate preparation will result in bond failure between the primer and the substrate.

The second important process involves forming the bond. This process requires precise timing and proper operator technique. A splice must be made within a one to two minute window of opportunity after applying the adhesive coat to the primed substrates. This is ample time for a small area, such as a drip edge or patch, but when splices get longer and wider the window of opportunity can disappear while applying adhesive to other areas of the splice. This creates a rush to make the bond and allows little time to verify proper splice alignment. After the splice is made, it must be stitched or rolled. Stitching and rolling both apply pressure to the spliced area, manually removing most air gaps and creating a stronger bond. Stitching must be performed vigorously for a number of minutes across the entire length of the splice.

Ambient conditions can affect structural adhesive bond performance. The chemical reactions that must take place to form a quality bond are subject to the substrate temperature. High humidity, low temperature, or a combination of both can adversely affect the strength of cold-chemical bonds. It is important that structural adhesives be used in accordance with manufacturer recommended environments if bonds are to be effective.

Testing of cold-chemical splices poses a difficult problem. Because splices are made individually, or in different heats, it is impossible to make a true witness piece. Proper testing and accurate results rely on an operator's consistent technique when forming bonds.

Failure of cold-chemical bonds occurs through the splice at the adhesive interface. The curve shown for peel 144 (Appendix A2) shows that the structural adhesive joining the two parts holds to a limit, then fails in a succession of recurring events. These jagged ridges represent tensile fractures at the adhesive interface and the relaxing of the part that follows before another bond site is stressed. Once total failure occurs, the individual pieces of drainage trough material are no longer joined and may allow water to leak onto the bridge structure and traffic below, necessitating total trough replacement.

Cold-chemical splices can be an acceptable alternative to hot vulcanization in some situations. At times, drainage trough systems are designed with vulcanized closed ends that cup upward. It may be physically impossible to make this type of closed end lay flat in a press. Cold-chemical vulcanization becomes the only viable method to manufacture these parts. From time to time, it is necessary to make splices in the field. Again, cold-chemical vulcanization lends itself to this type of application. Whatever the situation, it is necessary to have a trained operator make cold-chemical splices to ensure sufficient performance.

CONCLUSION

Both hot vulcanized splices and cold-chemical splices are currently accepted methods of bonding drainage trough components. The following is a comparison of the two methods:

Peel Test Standards

- Hot vulcanized bonds surpass the most stringent peel test standard by an average of 283%.
- Cold-chemical bonds surpass the same standard by a maximum of 50% and an average of 2.9%.

Manufacturing Process

- Hot vulcanized splicing employs a press and semi-automated controls to form a bond.
- Cold-chemical splicing depends on precise process timing and operator technique to form a bond.

Manufacturing Environment

- Hot vulcanized bonds are not affected by ambient conditions because the press will consistently input heat and pressure into the process.
- Cold-chemical splice quality is affected by ambient temperatures.

Test Procedures

- Hot vulcanized bonds are tested using a witness piece.
- Cold-chemical bond test accuracy relies on an operator's consistent technique when forming bonds.

Mode of Bond Failure

- Hot vulcanized splice failure leaves the bond intact and the product continues to function as designed.
- Cold-chemical splice failure separates at the bond line and may allow water to leak from the trough.

Hot vulcanization is the method of choice for creating drainage troughs at The D.S. Brown Company. The D.S. Brown Company prides itself in providing world-class products to all of its customers. A brief comparison of bond strengths summarizes why The D.S. Brown Company has standardized on hot vulcanization: it would take a force of 2,466 pounds (1.2 tons) applied perpendicularly to the direction of water flow to successfully peel apart a cold-chemical vulcanized drainage trough splice 60 inches long, compared with 9,204 pounds (4.6 tons) on an equivalent hot vulcanized splice. The D.S. Brown Company limits cold-chemical vulcanization to use in areas not accessible with a splice press. Specifying hot vulcanized splices and designing press accessible splices can help guarantee a quality product. Please consult The D.S. Brown Company for more information on specifying and designing hot vulcanized drainage trough splices and for drainage trough splice design considerations.

Appendix A1

Hot Vulcanization Test Results

Instron Application Laboratory

Company: Instron ASTM Method Set
Lab name: Instron Demonstration Lab
Operator ID: JSM
Test date: 10/22/2008

Specimen: HOT VULCANIZED
Number of specimens: 6
Temperature:
Humidity:

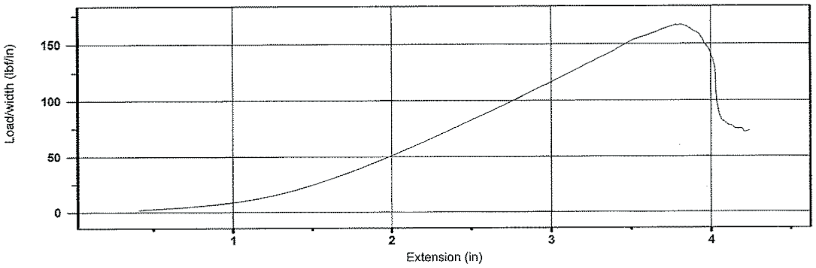
Note 1: NEOPRENE, HOT VULCANIZED

Speed: 2.00 in/min

Results

	Average Valu (lbf/in)	Mix Date	Max Load (lbf)	Test Info
PEEL25	154.259	N/A	153.5	NEO-10-RAW-BUFF
PEEL26	97.231	N/A	96.7	NEO-10-RAW-BUFF
PEEL27	181.429	N/A	180.5	NEO-10-RAW-BUFF
PEEL28	162.106	N/A	161.3	NEO-10-RAW-BUFF
PEEL29	158.541	N/A	157.7	NEO-10-RAW-BUFF
PEEL30	166.898	N/A	166.1	NEO-10-RAW-BUFF
Mean	153.411	0.00	152.6	0.00
C.V.	18.950	0.00	19.0	0.00

Curves ASTM D429



Appendix A2

Cold-Chemical Vulcanization Test Results

Instron Application Laboratory

Company: Instron ASTM Method Set
Lab name: Instron Demonstration Lab
Operator ID: JSM
Test date: 11/10/2008

Specimen: COLD-CHEMICAL VULCANIZATION
Number of specimens: 6
Temperature:
Humidity:

Note 1: NEOPRENE, COLD-CHEMICAL VULCANIZATION

Speed: 2.00 in/min

Results

	Average Valu (lbf/in)	Mix Date	Max Load (lbf)	Test Info
PEEL139	41.252	11-3-08	49.8	NEO-5-SC2000-BUFF
PEEL140	36.058	11-3-08	36.1	NEO-5-SC2000-BUFF
PEEL141	49.727	11-3-08	54.7	NEO-5-SC2000-BUFF
PEEL142	24.641	11-3-08	28.1	NEO-5-SC2000-BUFF
PEEL143	43.182	11-3-08	47.5	NEO-5-SC2000-BUFF
PEEL144	51.993	11-3-08	58.8	NEO-5-SC2000-BUFF
Mean	41.142	0.00	45.8	0.00
C.V.	29.537	0.00	25.3	0.00

Curves ASTM D429