Technical Report

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 United States Department of Transportation. Six samples of each splice method were tested to provide accurate 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 utilizes 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 soak the heat through all the plies of belting and bring the entire splice to the required temperature within a few minutes. The pressure also helps free sulfur agents crosslink with the bond sites by forcing them into close contact. 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 shown 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. This variability is compensated by the minimum test result. Peel 26 (97.231 lbf/in) passed the peel test standard by 143%. Variability exists in this process but is compensated by standard exceeding test results.

The process of hot vulcanization lends itself to quality. After being cut to size and prepared for splicing, press operators have ample time to line the splices up correctly. There is no rush to complete this most 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. Bonds are made under heat and high pressure. The result of this process is a quality splice.

Hot vulcanized splices are tested using witness pieces. Witness pieces are made and vulcanized in process with drainage trough splices. These witness pieces 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. In the rare event of failure, hot vulcanized splices will continue to join drainage trough sections together and prevent water leakage.

Hot vulcanized splices are the best choice for drainage trough splice vulcanization. Testing and field trials have proven this method to be superior to currently available alternative methods.

Cold-Chemical Vulcanization

Cold-chemical vulcanization utilizes a two-part rubber compatible structural adhesive system to bond drainage trough material together. 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 hardens the mixture. When properly applied, the structural adhesive facilitates bonding by providing a crossbridging agent. A crossbridging agent is a difuntional 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. Because a continuous piece of material is not being formed, all bonds made using structural adhesives are reversible across the adhesive interface plane. The chemical reactions created during cold-chemical vulcanization are shown in Figure 1.

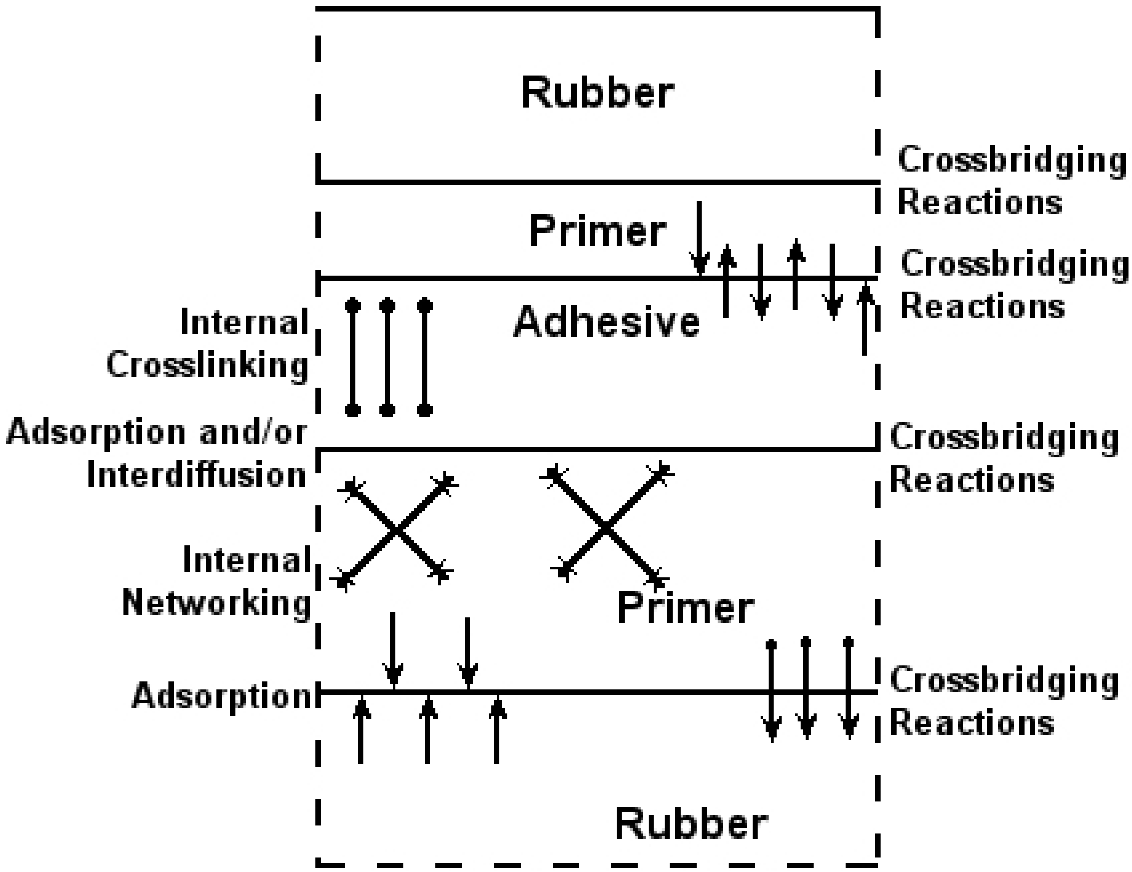


Figure 1 Anatomy of a Cold-Chemical Bonded Elastomer

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 high process variability, which ranges from failure at 38.4% below standard to passage at 30% above standard. This variability results in bond failure and can be attributed to process control and operator technique.

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 hence 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. Once the splice is made it must be stitched or rolled. Stitching and rolling both apply pressure to the spliced area to help it properly bond. This process is vital to forming a good bond. Stitching should be done vigorously for a number of minutes across the entire length of the splice to form a proper seal. There is no margin for error in operator technique and process timing. Any relaxing of procedures can easily result in a bond that does not meet designated requirements.

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. Splices are made individually and are subject to operator technique. Two splices may have very different test results due to minor differences in the manufacturing process. It is impossible to make witness pieces because they too would be distinct entities created separately from the actual part. Testing relies on the operator's consist use of the same technique for every bond made, including test samples.

Cold-chemical bonds show adhesive failure when peel tested. As can be seen in the curve shown for peel 139 to peel 144 (Appendix A2), the structural adhesive that joins the two pieces holds then gives in a succession of recurring events. Once total failure occurs, the individual pieces of drainage trough material cease to be 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 limited situations. At times drainage trough systems are designed with vulcanized closed ends that cup upward. It is 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 (please consult with the D.S. Brown Engineering Department for acceptable alternative designs to cupped closed ends). 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 important 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. Of the two splice method options, hot vulcanization stands out as the superior choice for the following reasons:

- 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%, leaving no margin for error.
- Manufacturing Process
  - Hot vulcanized splicing employs a press and semi-automated controls to form a bond. It does not rely heavily on operator skill for success.
  - Cold-chemical splicing depends on precise process timing and operator technique to form a bond.
- Manufacturing Environment
  - Hot vulcanized bonds can be made in nearly any environment because the press will consistently input heat and pressure into the process.
  - Cold-chemical splicing is subject to ambient temperatures and relative humidity.
- Test Procedures
  - Hot vulcanized bonds are tested using a witness piece.
  - Cold-chemical bonds samples are subject to operator technique and may not reflect actual splice values.
- 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, thereby necessitating total trough replacement.

Cold-chemical vulcanization is an inferior method to hot vulcanized drainage trough splices. A brief comparison of bond strengths summarizes hot vulcanization's superiority: 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-chemically vulcanized drainage trough splice 60 inches long, compared with 9,204.6 pounds (4.6 tons) on an equivalent hot vulcanized splice. Cold-chemical vulcanization should be limited to use in areas not accessible with a splice press. Drainage trough systems can be designed with press accessible splices to avoid cold-chemical splices. Specifying hot vulcanized splices can also help guarantee a quality product. Please consult the D.S. Brown Engineering Department for further information on drainage trough splicing and for drainage trough splice design considerations.

Appendix A1

Hot Vulcanization Test Results

Instron Application Laboratory

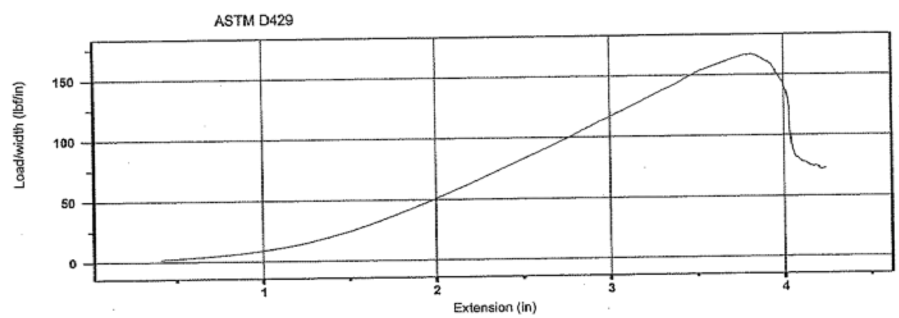
Company:	Instron ASTM Method Set	Specim HOT VULCANIZATION	
Lab name:	Instron Demonstration Lab	Number of specimens:	6
Operator ID:	JSM	Temperature:	
Test date:	10/22/2008	Humidity:	

Note 1: NEOPRENE; HOT VULCANIZED

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

Appendix A2

Cold-Chemical Vulcanization Test Results

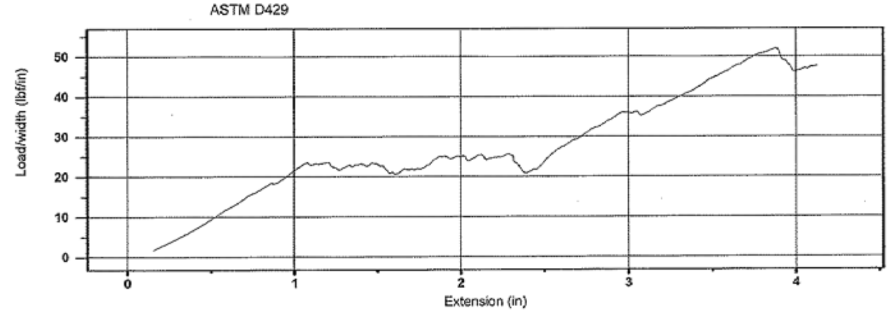
Instron Application Laboratory

Company:	Instron ASTM Method Set	Specimi	COLD-CHEMICAL VULCANIZATION
Lab name:	Instron Demonstration Lab	Number of specimens:	6
Operator ID:	JSM	Temperature:	
Test date:	11/10/2008	Humidity:	

Note 1: NEOPRENE Cold-Chemical VULCANIZED 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