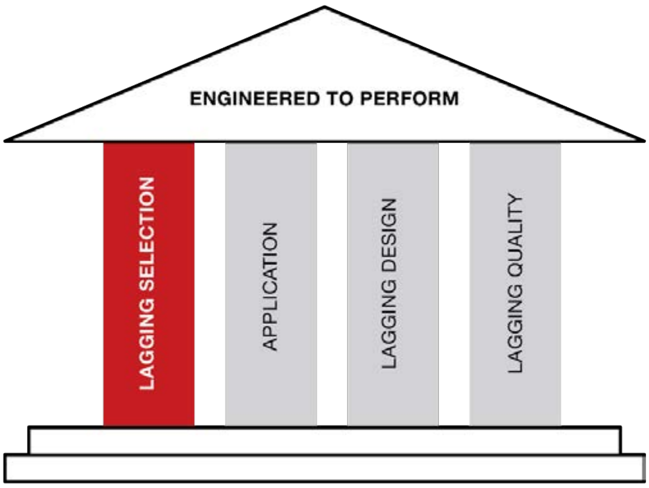
Hot vulcanising vs cold bonding for pulley lagging application – what are the differences?

Introduction

Cold bonded lagging has been used for more than fifty years largely, as a result of its ease and convenience of application. While hot vulcanized rubber lagging has also been used for many years, hot vulcanized ceramic lagging and polyurethane lagging are more recent additions.

Lagging selection is one of the four pillars required for engineered lagging to perform.



This technical bulletin provides details on the differences between hot vulcanized lagging and cold bonded lagging, and how these differences impact the end use performance."

Cold bonded lagging as the name suggests is a lagging application system that is done at room temperature. Normally this means temperatures between +15°C and +40°C. When ambient temperatures fall outside this range the applicators would normally take steps to adjust the work area temperature to fall within this range.

The main advantage of cold bonded lagging is that it can be done both in the field (i.e. on the conveyor) or in a workshop and, requires no specialized equipment.

Hot vulcanized lagging application involves curing the lagging at elevated temperature, typically 140-160°C for 3-6 hours. This necessitate the use specialized equipment called an autoclave (PHOTO #1) and can only be done in factory setting. Hot vulcanized lagging cannot be done in the field or with the pulley installed on the conveyor.

PHOTO #1

The main advantage of hot vulcanized lagging is that the process is much more robust than cold bonding, and as a result the adhesion of the lagging to the pulley is much stronger, consistently providing stronger rubber tear bonds.

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

The Differences Between Cold Bonded & Hot Vulcanised Lagging

The systems

The diagrams below show the cold bonded (Figure#1) and hot vulcanized (Figure#2) systems side by side. The hot vulcanized bonding system has additional uncured bonding layers that when activated by heat diffuse into and/or bond onto adjacent layers such as the steel pulley shell and the cured rubber backing of the lagging.

Cold Lagging Bonding System

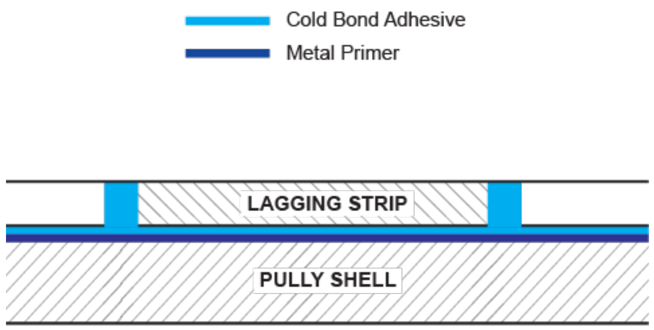


FIGURE #1

Hot Vulcanised Lagging Bonding System

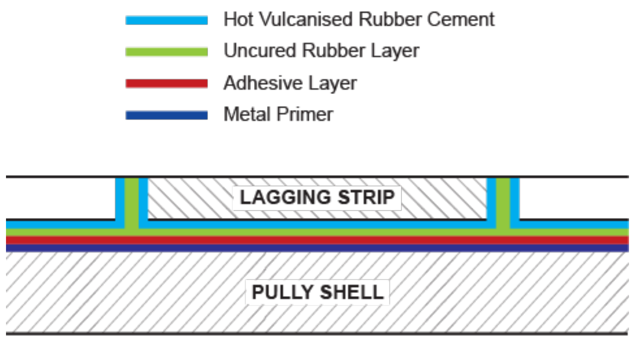


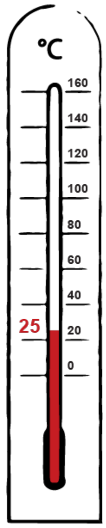
FIGURE #2

The application

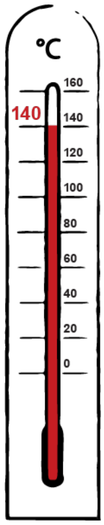
The differences between cold bonding and hot vulcanization are summarized in the following images:

CURING TEMPERATURE

Cold Bonding

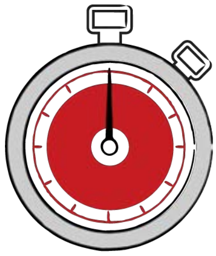


Hot Vulcanised



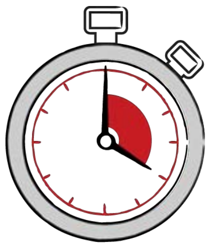
CURING TIME

Cold Bonding



24 HOURS

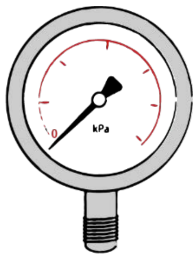
Hot Vulcanised



3-6 HOURS

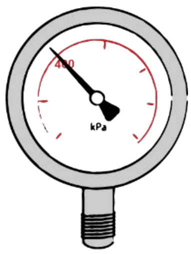
CURING PRESSURE

Cold Bonding



AMBIENT (0 KPA GAUGE)

Hot Vulcanised



400 KPA GAUGE

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

Cold Bonded Lagging Application to Pulley Shell

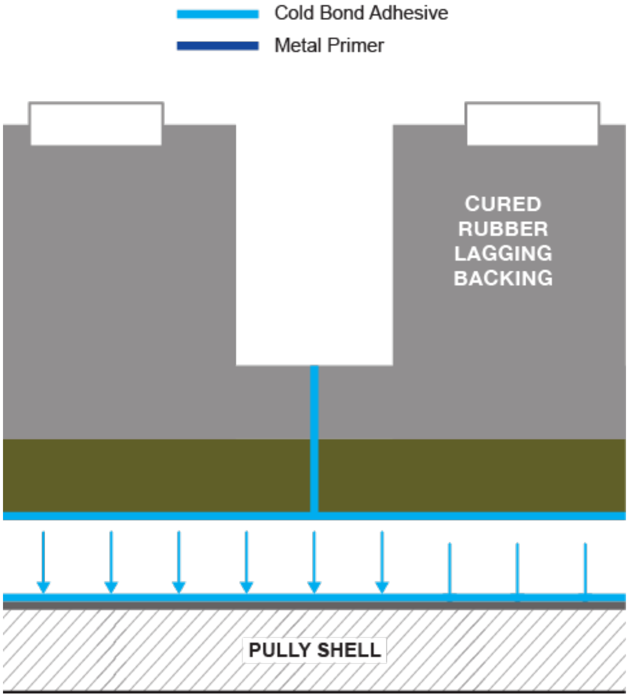


FIGURE #3

Hot Vulcanising System

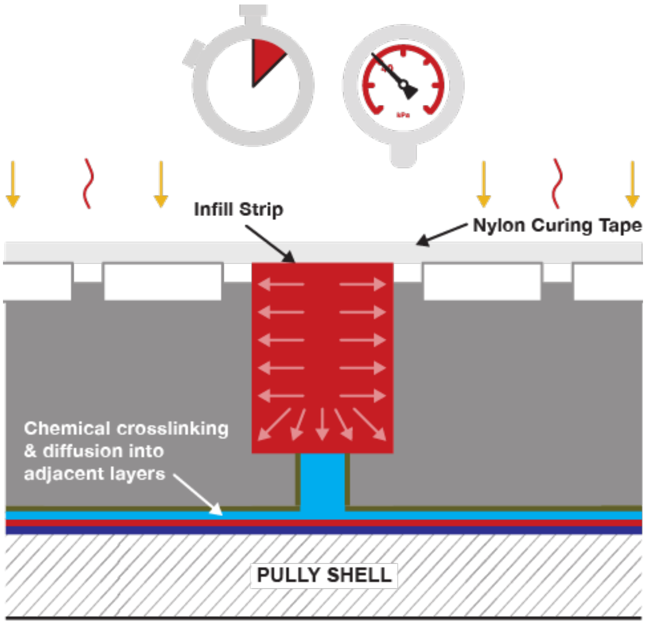


FIGURE #4

Cold Bonded Lagging Applied to the Pulley

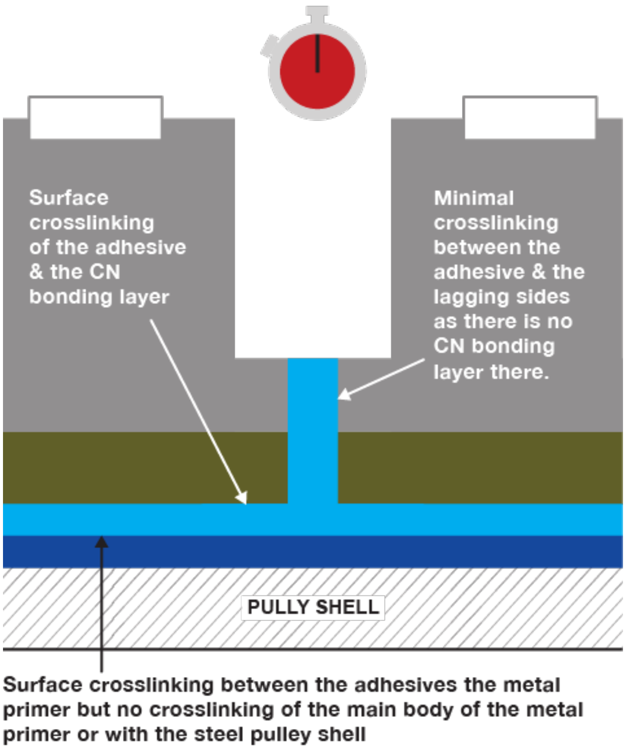


FIGURE #5

Hot Vulcanising System

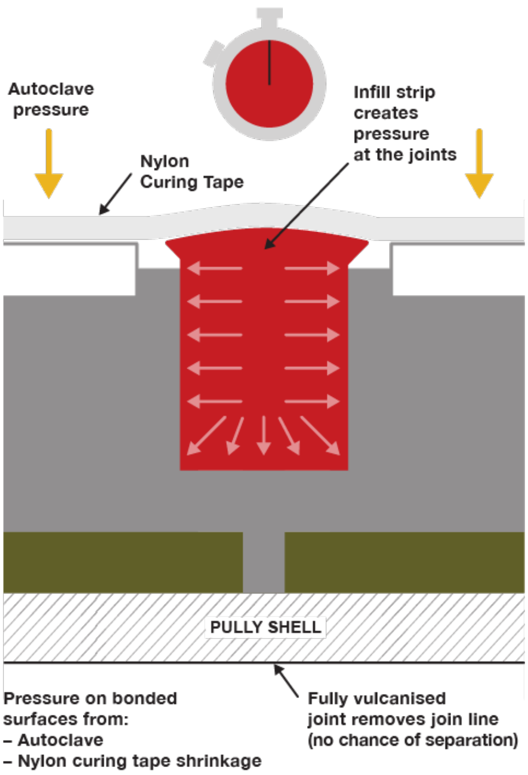
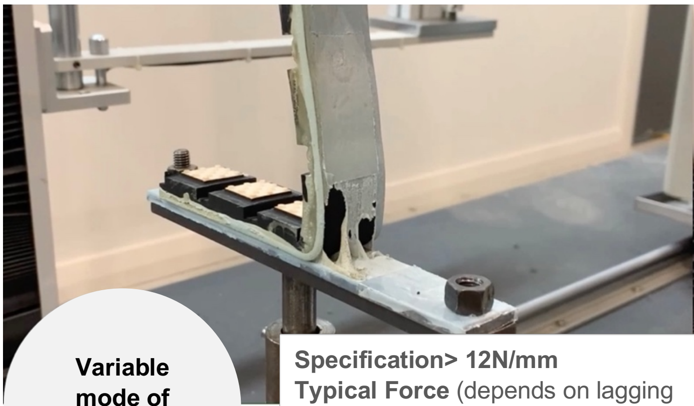


Figure #6

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

ADHESION STRENGTH

Cold Bonded



Hot Vulcanised

Variable mode of failure

Specification> 12N/mm
Typical Force (depends on lagging type and thickness) **9-15 N/mm**

Specification> 31 N/mm
Force 20-40 N/mm

Always 100% rubber tear failure

Cold Bonding Summary

Cold bond adhesion depends largely on a process called crystallisation that occurs within the two adhesive layers (one applied to the pulley shell, and one applied to the back of the lagging) immediately after the adhesive is applied and is drying. Crystallisation is a physical process within the adhesive layers that converts two separate layers into a single continuous layer. The rate of crystallisation is dependent on time and temperature - the variability in these two factors, in each cold bond lagging application contributes greatly to the variability in the adhesion strength that is inherent in this process. The addition of a chemical “hardener” is designed to provide some chemical attachment to the rubber backing layer and the metal primer. Because the lagging rubber backing layer is already vulcanised and the bonding process is carried out at room temperature and at ambient pressure, it is not possible for significant diffusion of the adhesive, metal primer and the rubber into each other, to occur. Figure 5 shows how the crystallisation and chemical reaction occurs largely in the adhesive layers with minimal chemical reaction and diffusion in the rubber backing of the lagging or into the metal primer on the steel pulley shell.

It is this lack of diffusion between the various bonding system layers that is a significant factor in the limits on the strength and consistency of the cold bond adhesion.

The following test results will give an indication of the variability in adhesion force that can be introduced into the cold bonding process:

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ADHESION STRENGTH

1. Adhesion strength – Testing time from Application of the Lagging to the Pulley Shell vs Ambient Temperature

TEMP (°C)	TIME (hrs)	ADHESION (N/mm)
10	4	4.0
10	8	6.9
10	12	8.9
10	24	11.8
10	96	15.9

TEMP (°C)	TIME (hrs)	ADHESION (N/mm)
20	4	6.3
20	8	9.8
20	12	11.4
20	24	14.6
20	96	16.2

TEMP (°C)	TIME (hrs)	ADHESION (N/mm)
35	4	8.0
35	8	11.4
35	12	14.4
35	24	16.1
35	96	16.5

2. Adhesion strength -Testing time from application of Last Coat of Adhesive to application of Lagging to the Pulley Shell

TEMP (°C)	TIME (min)	ADHESION (N/mm)
25	5	3.8
25	7	15.5
25	10	15.2
25	15	12.1
25	20	11.5

Applying the lagging to the pulley with insufficient time for the solvent in the adhesive to evaporate (5 minutes) causes low adhesion results as does having too long a drying time where the solvent has gone and the adhesive layer has partially crystallised before the application (20 minutes).

3. Adhesion strength with Age of Lagging CN Bonding Layer

BONDING LAYER AGE (Months)	ADHESION (N/mm)
> 24	6.4
1	15.8

NOTE: BUFFING OF OLD CN BONDING LAYER OR WIPING WITH TOLUENE SOLVENT CAN REPLICATE THE PERFORMANCE OF 1 MONTH OLD CN BONDING LAYER

4. Adhesion strength - Adhesive Application to Lagging Method – 1st Coat

BONDING LAYER AGE (Months)	APPLICATION METHOD	ADHESION (N/mm)
10	Vigorous	13.5
10	Passive	10.5
1	Vigorous	16.5
1	Passive	16.9

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5. Adhesion Strength vs Pulley Shell Surface Finish

SURFACE PROFILE (um)	ADHESION (N/mm)	MODE OF FAILURE
<50	7.8	100% AP
50-100	15.5	50-100% RT

AP = ADHESIVE TO PRIMER
RT = RUBBER TEAR

6. Impact of Dew Point on Adhesion Strength

PULLEY/LAGGING TEMPERATURE VS. DEW POINT (°C)	ADHESION (N/mm)
> 5	> 12.0
< 5	2 - 9

Evaporation of the solvent during application of the metal primer and/or the adhesive can cause moisture to condense on the bonded surface when the temperature is within 5 C of the dew point.

Hot Vulcanised Summary

Hot vulcanized lagging is also applied at room temperature with similar steps to those above, but with the final curing process done in a pressure vessel called an autoclave at an elevated temperature of 140-160°C. The differences between the cold bonded and hot vulcanized application process detailed above result in a number of performance outcomes, specifically:

1. The elevated temperature (130-140°C) initiates a series of chemical reactions between the steel pulley shell and the metal primer, the metal primer and the rubber adhesive, and the adhesive and the lagging. There is significant diffusion and reaction of the curing chemicals between all the bonding layers (metal primer, adhesive, rubber cement, uncured bonding layer and the precured rubber backing layer). These reactions result in very strong chemical bonds.
2. The elevated pressure in the autoclave over several hours maximises and ensures good contact between the lagging and the pulley shell which increases adhesion.
3. The wet nylon curing tape shrinks as it dries out at the elevated temperature which applies substantial pressure over the whole pulley surface and in particular over the joints.
4. High pressure on the lagging and on all the bonding surfaces as a result of the autoclave pressure, shrinkage of the wet nylon curing tape as it dries and the increase in volume of the lagging due to thermal expansion as the temperature increases from ambient to 140°C.
5. Rubber tear chemical bonds over the entire pulley surface and a and at the joints between strips – effectively the joints between strips disappear as shown in the photo below:

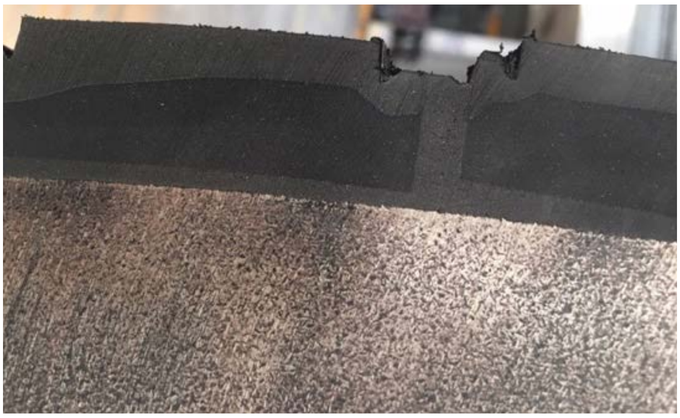


PHOTO #3

IMPORTANTLY NONE OF THE ABOVE OUTCOMES OCCUR WITH COLD BONDED LAGGING APPLICATION

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

What does this mean for pulley performance?

Mining technology is rapidly evolving to meet the challenges of extracting minerals in remote locations, often with extremes of weather and often from ore bodies located deep underground. To achieve production costs that are competitive, and sustainable, a number of new technologies are being adopted by the major mining companies – these include increasing use of automation and the use of high-powered gearless drive conveyors for their transportation requirements.

To maximise the effectiveness of these technologies the reliability of the equipment becomes critical to ensuring target production costs and production output are achieved. For conveyor pulleys this has necessitated the use of pulley lagging that can handle the increased loads applied by high power drive systems, extremes of temperature from -50°C to +75°C, and in many cases operation in extremely wet and corrosive environments.

Traditionally many pulleys have been lagged with cold bonding systems which were convenient to use and did not require the use of specialised equipment – effectively convenience was given priority over performance.

Today the costs of unplanned conveyor down time are enormous – for example for a conveyor transporting 10,000 tonnes/hour of ore worth $US 100.00/tonne, and operating 24/7, unplanned conveyor down time costs the mining company $US 1,000,000/hour.

For past five years Elastotec has collected data from our network of Approved Applicators on the modes of lagging failure that are seen on pulleys sent for refurbishment. The most common modes of failure are:

- wear
- debonding from the pulley shell
- edge lifting
- corrosion at the joints between lagging strips leading to lagging debonding
- ceramic tile loss due to de-bonding

It has been well documented that cold bonding of pulley lagging increases the likelihood of premature lagging failure due to de-bonding from the pulley shell, edge lifting, and corrosion of the shell at the joints between lagging strips. These types of failures, can in many cases, require re-lagging on the conveyor, with loss of production. Because the conditions for lagging on the conveyor are less than ideal these problems often re-occur.

For the corrosion failure at the joints between lagging strips this can also result in additional unnecessary expense when the depth of the corrosion reduces the shell thickness below what is required for the designed operating loads, and the pulley has to be scrapped.

PHOTO #4

PULLEY SHELL PITTING FROM CORROSION DUE TO WATER INGRESS BETWEEN LAGGING STRIPS

Three of the most common causes of failure with cold bonding are:

1. Debonding of lagging from the pulley shell

Debonding from the pulley shell is a catastrophic failure that occurs most commonly on drive and high-tension bend pulleys when the force applied to the lagging exceeds the adhesion strength of the bond between the lagging and the pulley shell.

A common standard for cold vulcanised bonding is an adhesion of 9 N/mm – ideal conditions in factory application, with everything done correctly can provide adhesion from 9

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

to 15 N/mm. However, when lagging is cold vulcanised without OEM application procedures, or in poor conditions (on the conveyor), in many cases adhesion is below the standard of 9 N/mm.

All that is required for the lagging to debond is for the shear forces applied to the lagging to be greater than the adhesion of the lagging to the pulley shell.

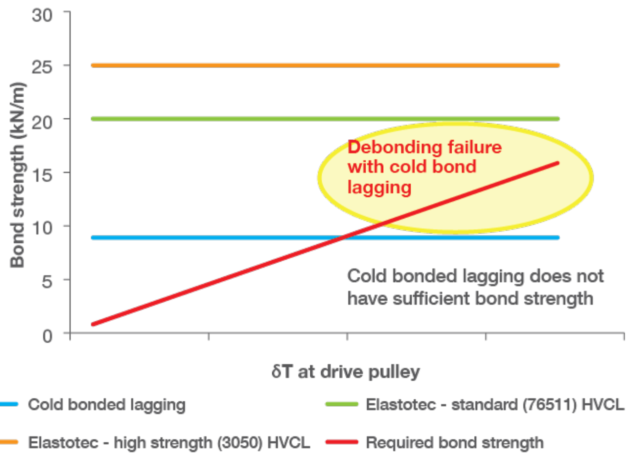


FIGURE #7

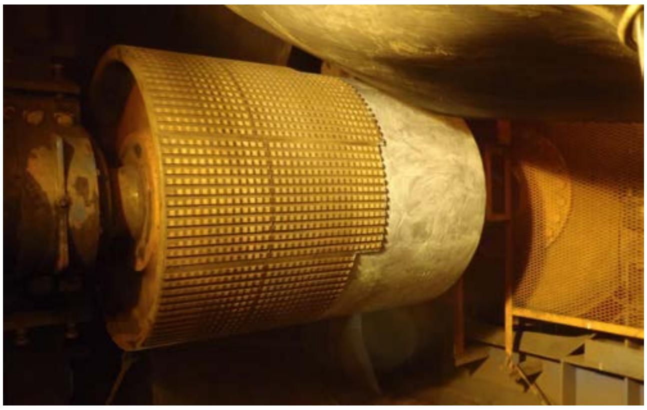


PHOTO #5

LARGE DRIVE PULLEY WITH COLD VULCANISED CERAMIC LAGGING THAT HAS DEBONDED FROM THE PULLEY SHELL UNDER LOAD

PHOTO #6

CATASTROPHIC CERAMIC LAGGING FAILURE DUE TO DEBONDING FROM THE PULLEY SHELL

An additional factor that increases the likelihood of failure with cold bonded lagging is presence of localised shear forces. In drive pulleys as the T1/T2 ratio increases the cyclic shear forces that the lagging is exposed to increase. Cold bond lagging has a lower tolerance to these cyclic shear forces than hot vulcanised lagging and so conveyor working conditions such as stop/start operation or higher loadings when production tonnages are increased can result is de-bonding that would not occur with hot vulcanised lagging. The photos below show a pulley with cold bonded lagging that failed within two weeks of installation at a new site. The conveyor was being set up so there was a lot of stop/start operation with a high T1/T2 ratio (>4).

PHOTO #7

DRIVE PULLEY COLD BOND LAGGING FAILURE AFTER TWO WEEKS FROM INSTALLATION ON A NEW CONVEYOR WITH STOP/START APPLICATION

A number of factors combine to magnify the chance of a debonding failure – these include:

- The loads on pulley lagging are cyclic and move from zero to full load many times a minute, dependent on the pulley rpm. This dynamic action is far more severe than an applied static load.

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

- Start-up loads, particularly with a loaded conveyor belt will be much higher than the normal running load.
- Low temperatures cause the rubber belt covers and the rubber component of any pulley lagging to become stiff and less flexible. The lower the temperature the greater the extent to which this occurs. This loss of flexibility concentrates the applied loads on the weakest part of the cold vulcanised lagging – the bonding system.

The photos below show a pulley with cold vulcanised lagging that failed shortly after installation in operating conditions at -35°C. Note the raised rubber pips on the surface of the pulley are still intact and have not had time to be worn away.

PHOTO #8

COLD VULCANISED LAGGING FAILURE DUE TO DEBONDING UNDER LOAD AT LOW TEMPERATURE

Similar de-bonding failure can occur on non-drive pulleys that are subject to high localised shear forces – this is most commonly seen in pulleys that contact the dirty side of the belt but can also be seen on snub pulleys and turnover pulleys (refer to the photo below).

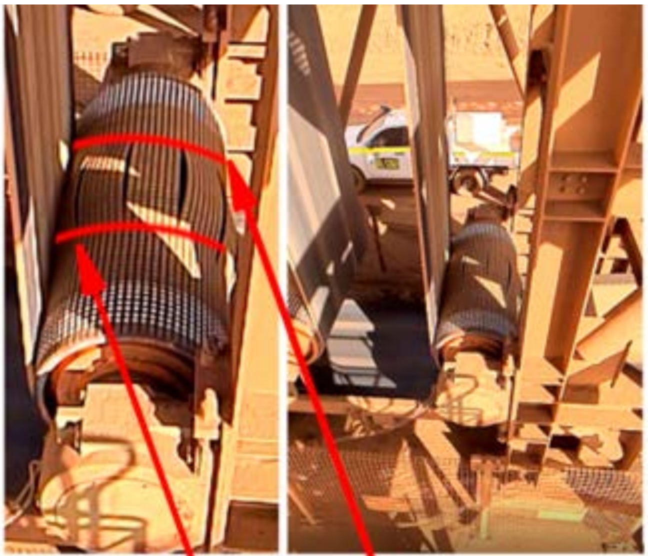
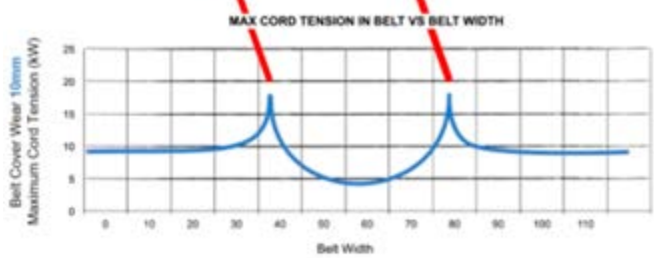


PHOTO #9



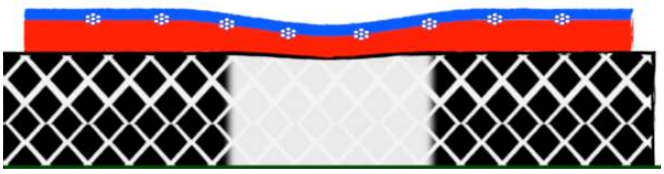


FIGURE #8

For pulleys that contact the dirty side of the belt the localised shear forces are generated by the uneven profile that results from the belt cover wear with increasing levels of wear leading to increasing localised shear forces. A detailed technical paper on this issue is available from Elastotec ELA1220-High Tension Bend Pulleys.

Testing adhesion on pulley lagging

Many lagging applicators using the cold vulcanised application technique for applying pulley lagging do not measure the adhesion strength obtained on each pulley, and so have no idea as to the adhesion being achieved on each installation.

Elastotec Hot Vulcanised Ceramic Lagging (HVCL) provides a guaranteed 100% rubber tear bond between the lagging and the pulley shell that achieves 20-25 N/mm adhesion strengths – roughly double the adhesion that can be obtained through cold vulcanised lagging application under ideal conditions.

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

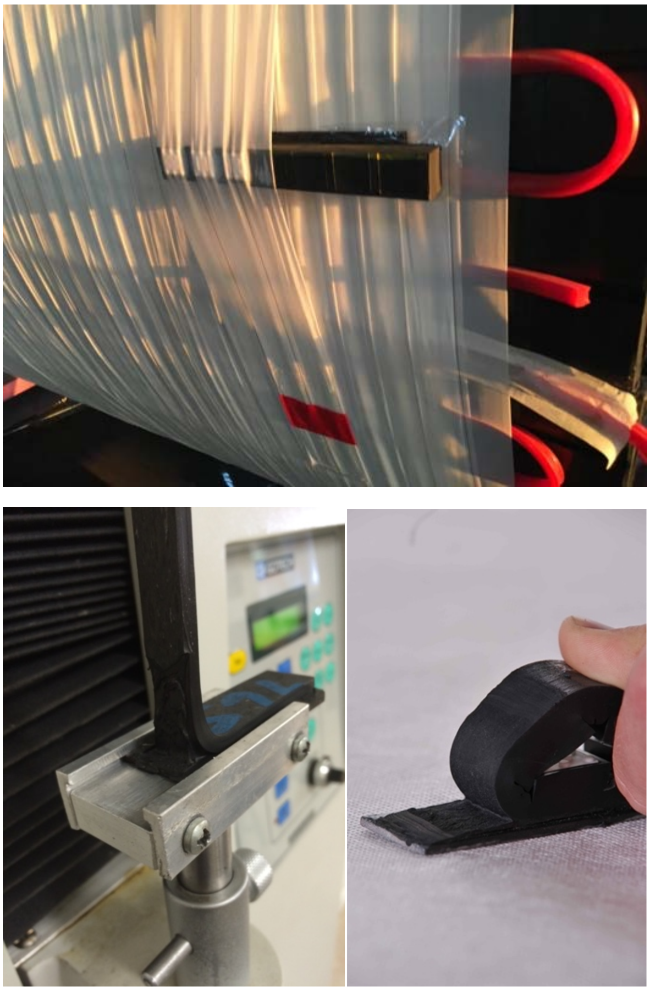


PHOTO #10

100% RUBBER TEAR BOND OBTAINED WITH HOT VULCANISED LAGGING APPLICATION AND TESTED ON EVERY ELASTOTEC LAGGED PULLEY

The following photo shows a common method of removing cold vulcanised lagging from the pulley shell by applying a load to the lagging at 90 degrees to the pulley.

PHOTO #11

For Elastotec HVCL the bond is so strong that if this technique is tried the pulley can be lifted by the lagging or the lagging will tear – there is no debonding from the pulley shell.

With 100% rubber tear adhesion debonding of the lagging from the pulley shell does not occur. Elastotec currently has more than 500 pulleys in the field with this bonding system with a number of installations on conveyors running high power gearless drives (up to 6,000 kW) and to date there have been no debonding failures.

Hot Vulcanised lagging application eliminates the chance of debonding from the pulley shell.

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

2. Edge lifting

Edge lifting of pulley lagging is a common mode of failure for pulleys operating in wet or corrosive conditions that have cold vulcanised pulley lagging.

PHOTO #12

In many cases of edge lifting failure the pulley lagging itself is still fully serviceable – the photo below shows a pulley lagged with cold vulcanised polyurethane and put into service in a coal wash plant. Shell corrosion has started at the shell end and has resulted in the lagging separating from the pulley in this area. The photo also shows that the lagging is not worn and would be serviceable if the edge lifting had not occurred.

PHOTO #13

EDGE LIFTING OF COLD VULCANISED PU LAGGING OPERATING IN A COAL WASH PLANT

The following photo gives an indication of one of the mechanisms for this failure.

PHOTO #14

FAILED PULLEY WITH COLD VULCANISED LAGGING REMOVED TO SHOW EDGE CORROSION RESIDUAL ADHESIVE PATTERN

The light grey pattern is where a layer of adhesive remains on the pulley shell after the lagging has been removed. This corresponds to recesses in the lagging profile. The areas that have no adhesive are the raised sections of the lagging which have been hammered down during the cold vulcanising application process.

This has resulted in greater contact and adhesion between the lagging and the pulley shell directly below the raised lagging areas, and lower contact and adhesion in the recessed lagging areas. When the pulley shell ends are exposed to wet conditions the water is able to penetrate between the lagging and the pulley shell at the areas below the recessed lagging profile. Once shell corrosion begins it quickly spreads around the shell end and the lagging lifts from the pulley shell and is easily damaged (see photos below).

PHOTO #15

SEVERE LAGGING DAMAGE DUE TO EDGE LIFTING AND BELT TRACKING

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

The two photos below show the results of operation at the same mine site of a pulley lagged with cold vulcanised ceramic lagging and one lagged with Elastotec Hot Vulcanised Ceramic Lagging. Both pulleys were installed at a large copper mine and operated in wet conditions where the water was acidic. There is corrosion evident on the end discs and locking elements of both pulleys. On the pulley with the cold vulcanised lagging there is severe edge lifting failure. The pulley with the HVCL shows no sign of edge lifting and the lagging remains fully serviceable.

PHOTO #17

COLD VULCANISED APPLICATION

PHOTO #18

HOT VULCANISED APPLICATION

Hot Vulcanised lagging application eliminates the chance of lagging failure due to edge lifting.

4. Joint failure

The joints between lagging strips are another weak point that regularly led to lagging failure. There are two main contributors to joint failure with cold vulcanised lagging application:

- Application techniques and workmanship
- Forces applied to the lagging joints by the belt during operation.

With regard to application techniques and workmanship many lagging applicators use a technique called "butt" lagging where each lagging strip is "butted" up against the previous strip. Depending on the skill and care of the operator the result can vary from having no gap between strips to having a gap several mm wide (see photo). It is common for lagging applicators to use liquid sealants such as "Sikaflex" to fill in gaps at the joins – the use of sealants to fill gaps will ensure lagging failure in wet conditions.

PHOTO #19

COLD VULCANISED LAGGING GAP BETWEEN LAGGING STRIPS

Even when the "butt" application method is done perfectly the sealing of the joint relies entirely on the cold vulcanised adhesive. When this method is used on pulleys with a "crown" the lagging is stretched into place to close up the join. The resultant join has the lagging under tension with the lagging strips trying to pull away from one another. Eventually these joins will open up allowing water to reach the pulley shell and corrosion to start.

The reason that the "butt" lagging method is commonly used is that it is the quickest application method and so gives the applicator the lowest cost. This low-cost application method substantially compromises the lagging service life.

When we look at forces applied to the lagging joints by the belt during operation, we see that the belt applies a load to the lagging – the highest loads occur on drive pulleys and on high tension bend pulleys.

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As the belt comes onto the pulley these loads act in a way that wants to open up the joins between lagging strips. When the pulley is operating in a wet environment this opening of the join, coupled with the hydraulic force generated by water caught between the belt and the pulley lagging, results in water reaching the pulley shell and causing corrosion.

Eventually this corrosion leads to debonding of the lagging along the joints – see photos below.

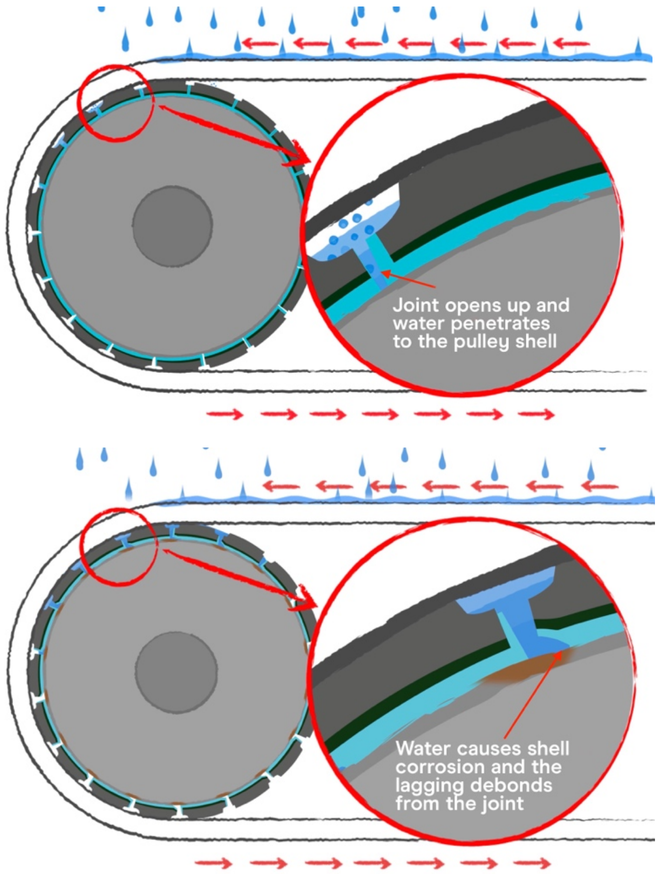

FIGURE #9

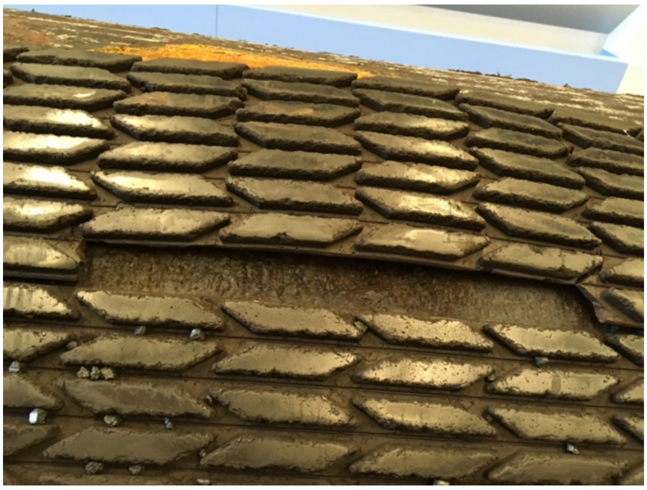

PHOTO #20

CORRO/SION AND LAGGING DEBONDING AT JOINTS BETWEEN COLD VULCANISED LAGGING STRIPS DUE TO WATER PENETRATION

When hot vulcanised lagging is applied to the pulley shell there are no joints between the strips as the unvulcanised bonding layer along the edge of each strip fuses together to form a continuous lagging sheet with no joins or weak points between strips.

This eliminates the chance of lagging failure at the joints between lagging strips.

HOT VULCANISING VS COLD BONDING FOR PULLEY LAGGING APPLICATION

PHOTO #21

HOT VULCANISED JOIN COMPLETELY SEALED FROM THE LAGGING SURFACE TO THE PULLEY SHELL – NO CHANCE OF SEPARATION OR WATER PENETRATION

Hot vulcanised lagging eliminates joint failure and the resultant debonding of the lagging and corrosion damage to the pulley shell.

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