

Conveyor Belt Bottom Cover Failure from Idlers and Pulleys

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Abstract

Excessive belt bottom cover wear from improper idler arrangement and ceramic pulley lagging can lead to early belt failure and unplanned downtime. This article discusses several failure modes and related field examples: bottom cover damage at idler junction due to severe bending, belt cover damage due to high normal and shear stress, accelerated bottom cover wear from misaligned idlers, and cover damage from problematic ceramic pulley lagging tiles. The idler junction bending is analyzed using finite element modeling. The idler junction pressure index is introduced as a design tool to limit the idler junction stress during the engineering stage.

Introduction

Belt conveyors are efficient and reliable material handling systems. The rubber belt with synthetic fabric or steel cord carcass is typically the most expensive single component of a conveyor. The belt also plays a dominating role in the ownership cost and reliability of a conveyor (1). While conveyor belts with more than 15 years of service life are not unusual, premature belt failure can also happen due to accidents, engineering or maintenance issues. The top cover, carcass and bottom cover can all be subject to premature failure or damage. The top cover usually suffers from damage related to transport material or tramp metal. The belt carcass may suffer from steel cord breakage and carcass penetration. The belt bottom cover does not contact transport material, instead the bottom cover makes countless rolling contact with idlers and pulleys. As a result, premature bottom cover failure typically starts from the interaction between the belt and the idlers and pulleys. This article discusses several scenarios of early belt bottom cover failure.

Cover Failure at Idler Junction

General Analysis

The conveyor belt bends at the junction between idler rolls. The bending creates compression in the belt's top cover and tension in the bottom cover. The extent of this deformation depends on the idler arrangement, belt properties and belt loading. Figure 1 shows a finite element analysis of the deformation in a steel cord belt on three-roll trough (idler set not shown in the figure). The idler junction bending area is along the belt travel direction, symmetric along the belt center line, and separates the belt's contact between the center roll and wing roll. Deformation in the idler junction area is mainly due to bending. Deformation in the idler contact area is mainly compression from the material and belt load, and shear from rolling resistance. The red dots in the idler contact area are high pressure points directly under individual steel cords, which relates to a different type of bottom cover failure.

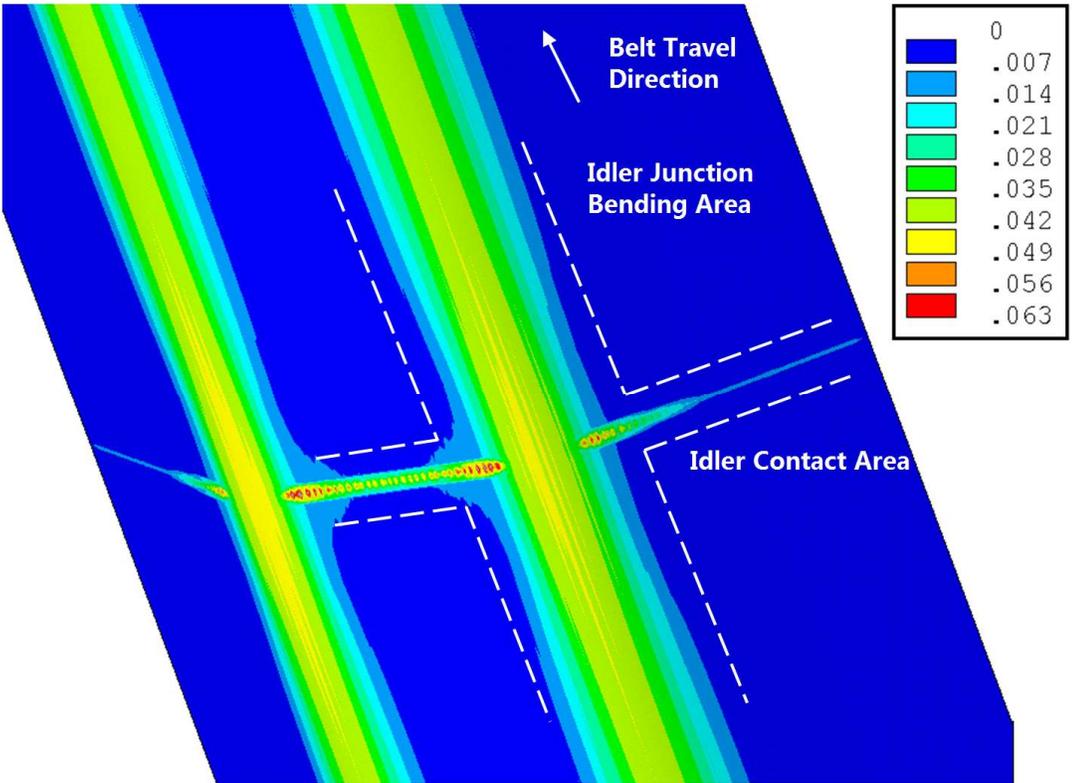


Figure 1. Equivalent (von Mises) strain in the belt bottom cover of a steel cord belt from finite element modeling.

High tensile strain in the bottom cover, due to severe bending at the idler junction, can facilitate surface cracks. The surface cracks may develop from short lengths to long stretches and further coalesce to cause deep cover failure. An example of this idler junction failure is illustrated in Figure 2. Some belt manufacturer's manual mentions this type of failure without detailed analysis (2).



Figure 2. Idler Junction Cover Failure

The bending at an idler junction is affected by several factors: trough angle, belt thickness, cross sectional loading of belt, material surcharge angle, idler spacing, and convex and concave curve. Increased bending can be characterized by a smaller radius of the bending curvature, and less bending by a larger radius of the bending curvature. The following is a list of the main factors that influence the idler junction bending.

Trough Angle: A steep trough angle like 60° increases the bending, compared to a shallow trough angle like 35° .

Belt Thickness: A thicker belt reduces the idler junction bending, because the bending stiffness is increased.

Material Cross Sectional Loading and Idler Spacing: Heavier combined weight of material loading and belt, for which the weight of material is typically the dominating component, increases the idler junction bending. The bending strain in the idler junction is highest when the belt is right on top of idler rolls. The bending relaxes between idler stations. This relaxation is referred as the belt flexure (3). By the same argument, because idlers provide support to the belt, wide idler spacing increases the idler junction bending.

Material Surcharge Angle: The material surcharge angle affects the idler junction bending. High angles create a heaped pile of material in the trough belt, which increases the material loading pressure at the middle of the center roll and reduces the loading pressure around the idler junction and vice versa.

Vertical Curves: At vertical convex curves, a component of belt tension is added to the belt weight and material loading in the gravitational direction, pushing the belt against idler rolls, so the idler junction bending is increased. A concave curve reduces the idler junction bending because the vertical component of belt tension is subtracted from the weight load.

Idler Configuration: For an inline idler arrangement, where all rolls are at the same plane, there is a gap between adjacent idler rolls. If the gap is wide enough and the belt's idler junction bending is severe enough, the belt can contact the idler edge. Figure 3 shows an example of a belt contacting the idler edge. When this scenario occurs, the idler edge acts like a knife edge, where the contact stress between belt and idler edge is very high and leads to high rate of cover wear. An improved design is the offset idler arrangement, where the rolls are staggered to create an overlap at the idler junction. This eliminates any potential contact between belt and idler edge. A large diameter idler roll reduces the contact stress between belt and idler, and the idler junction bending is reduced. For the same belt width, a five-roll trough arrangement reduces the idler junction bending, compared to a deep trough three roll arrangement, because there are additional idler junctions so the bending angle at each idler junction is reduced.

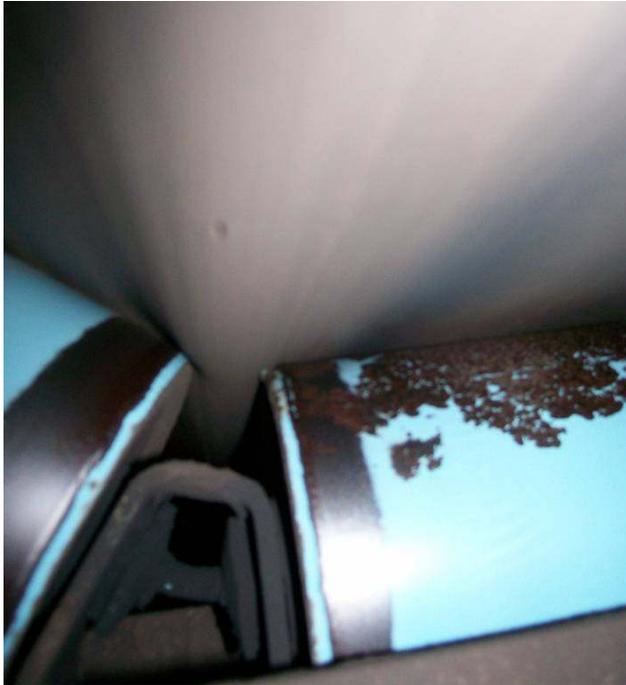


Figure 3. Belt Contacting Idler Edge

The length of an idler roll can affect the idler junction bending. For a typical three or five roll trough, the idler length is equal. Non-equal roll lengths are also implemented in overland conveyors (4). One reason is to change the load distribution between the wing roll and the center roll to a more optimal level. The material cross sectional loading capacity is also affected by the length of the idler roll. If the center roll length is decreased, the idler junction bending is increased.

Idler Junction Pressure Index

CDI developed the Idler Junction Pressure Index (IJPI) as a quantitative tool to indicate the idler junction bending stress. The IJPI allows the designer to explore various conveyor and belt parameters like idler spacing, diameter, roll lengths, belt speed, belt thickness, etc., to arrive at an optimized design while maintaining allowable idler junction bending. Higher IJPI values mean more bending deformation. As a general design criterion, the IJPI should not exceed 1.0~1.2 range. Figure 4 shows a finite element modeling of the idler junction bending in a 1200mm wide, 13.5mm thick belt on a 35° degree trough. The material loading is adjusted to achieve four different IJPI values, from low to high. It is obvious that the strain and idler junction bending increase with higher IJPI value from 0.61 to 1.59. IJPI =1 can be

viewed as a relatively conservative limit. When IJPI exceeds 1.2, the belt bending becomes severe. At IJPI=1.59, the belt starts to contact the idler edge.

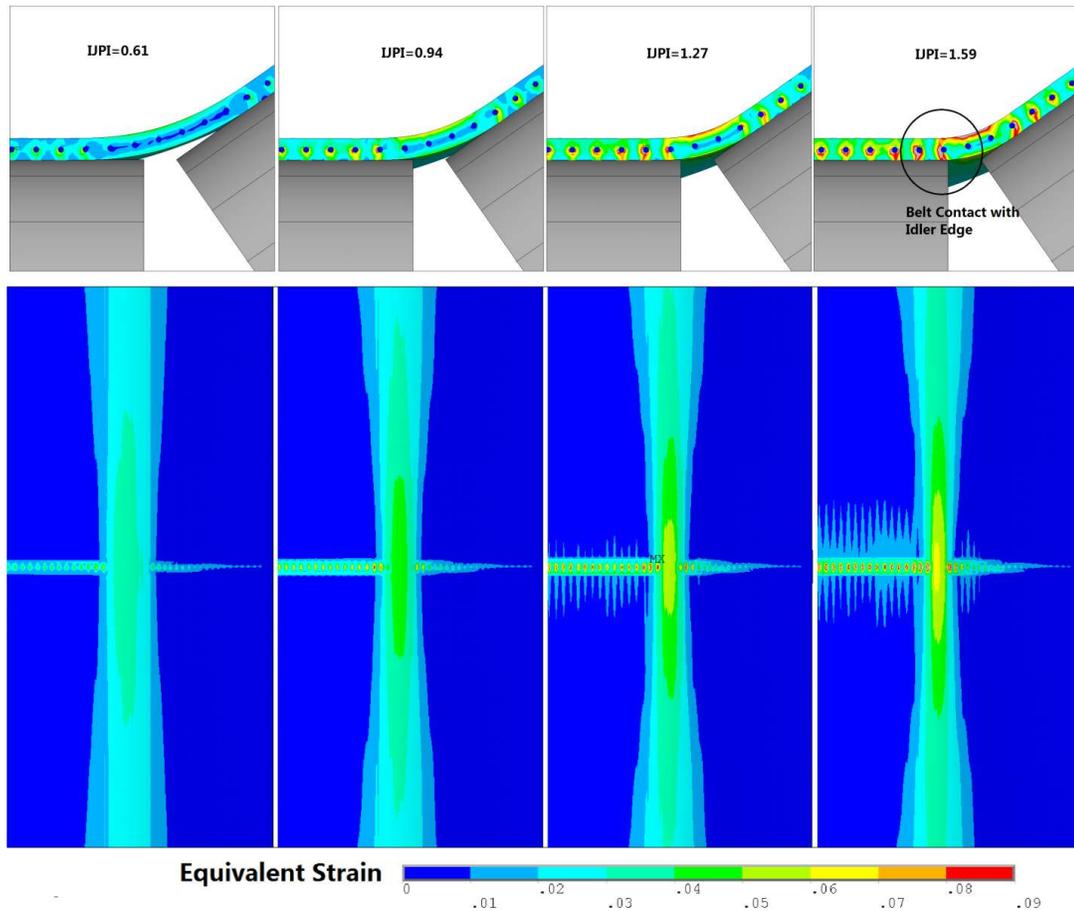


Figure 4. Finite element modeling of belt deformation with Idler Junction Pressure Index (IJPI). The top four graphs show the cut plane of a belt near the idler junction area. The bottom four graphs are the corresponding view of the belt bottom cover (looking from beneath the belt bottom cover)

To illustrate the relationship of IJPI to conveyor and belt parameters, Figure 5 shows different IJPI on the same 1200mm wide belt, at 70% CEMA loading and 5m/s belt speed, but with varying idler spacing, belt thickness, trough angle and tonnage. Some weight related factors, like idler spacing and tonnage, show a linear relation to IJPI. Some bending related factors, like belt thickness and trough angle, show a non linear relation to IJPI. For example, the IJPI increases beyond a linear relationship with reducing belt thickness.

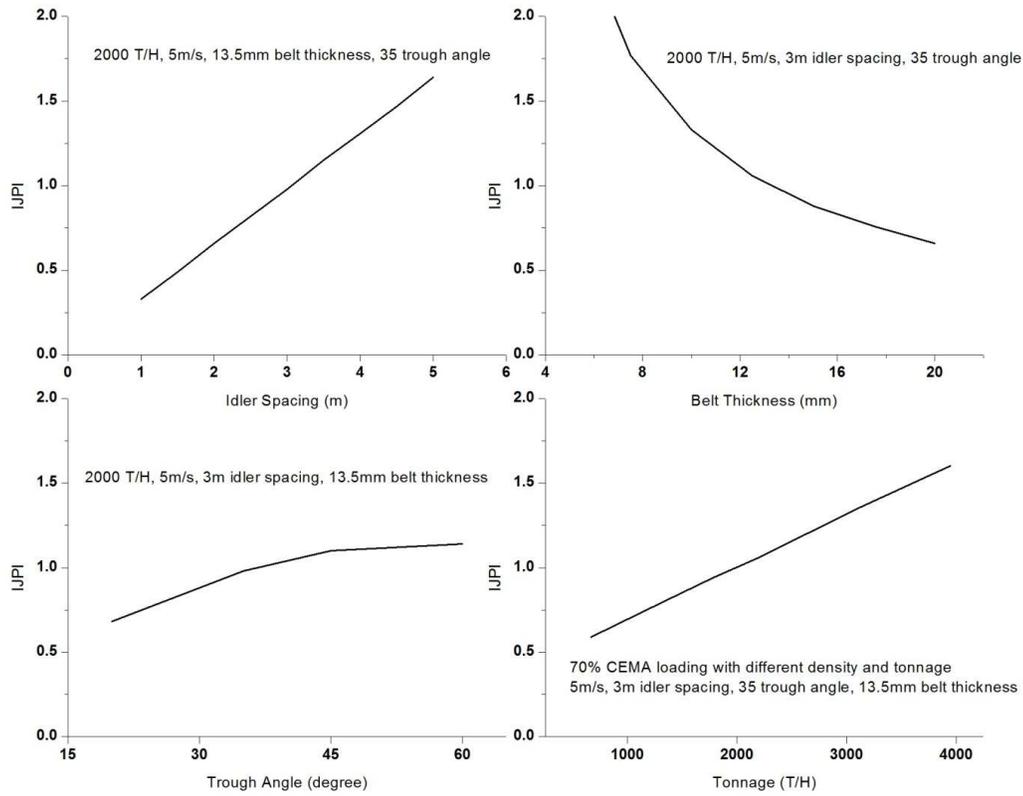


Figure 5. Idler Junction Pressure Index (IJPI) vs Idler Spacing, Belt Thickness, Trough Angle and Tonnage. Belt width is 1200mm for all cases.

The design limit on IJPI is derived from studying belt behavior and service life on running conveyors. High IJPI should be mitigated by design changes like reducing idler spacing, increasing belt thickness or increasing belt speed. Figure 6 compiles the IJPI of selected overland conveyor projects that CDI has worked on. Major system details of these conveyors are listed in Table 1.

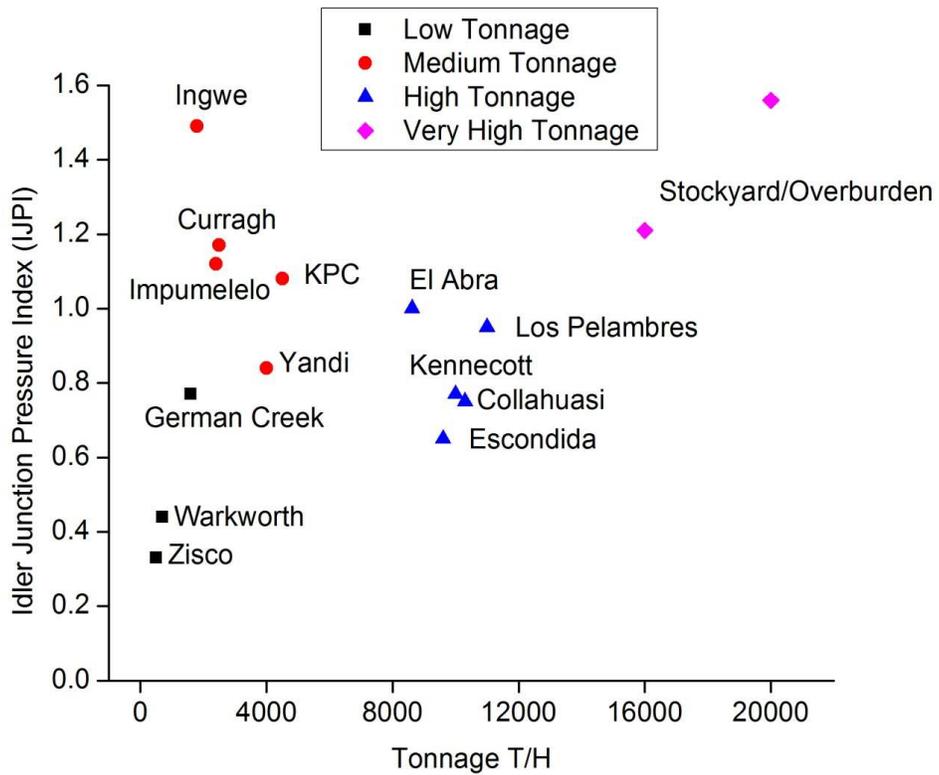


Figure 6. Project Examples of Idler Junction Pressure Index

Table 1 Selected System Details for IJPI Calculation

Project Name	IJPI	Tonnage (T/H)	Belt Speed (m/s)	Belt Width (mm)	Belt Thickness (mm)	Trough Angle	Idler Spacing (m)	Conveyor Length (km)
Zisco	0.33	500	4.5	750	14	25°	5	15.6
Iron Ore								
Yandi	0.84	4000	5.5	1200	19	45	2.5	4
Iron Ore								
Impumelelo	1.12	2400	6.5	1200	17	45	4.5	27
Coal								
Curragh	1.17	2500	7.5	1200	16	45°	5	20
Coal								
Ingwe	1.49	1800	5	1050	14	45°	4.5	8.9
Coal								

Los Pelambres	0.95	11000	7	1800	42	40°	1.5	12.8
		Copper Ore						
Escondida CV102	0.65	Copper Ore	6.1	1600	36	35°	1.5	3.8
Overburden	1.56	20000	3.15	2800	28	35°	1	1~3
		Overburden						

Some conveyors may have undergone modifications or upgrades so the parameters may not be current. There are four categories of conveyors: first is low tonnage conveyors (<1000 T/H). Because the tonnage is low, the IJPI is low as well, even with a thin belt and extended idler spacing at 5m. The second category is medium tonnage conveyors between 1500 T/H and 4000 T/H. Conveyors in this category can have a wide range of IJPI. This is due to the wide variations in system parameters like belt rating, idler spacing, belt speed, etc. For conventional conveyor design using short idler spacing, the IJPI is expected to be low. Conveyor design can also be optimized to reduce capital and operating cost, which includes reducing belt thickness and width, increasing belt speed and idler spacing, and utilizing low rolling resistance belt to reduce power consumption. The IJPI is typically increased in an optimized conveyor design, compared to the conventional design with reduced idler spacing. It is the conveyor designer's responsibility to make sure the IJPI is within the allowable limit. The third category is high tonnage overland conveyors that are operating in some South American copper mines. Although the tonnage is high, beyond 8000 T/H, the belt thickness is also typically increased by having large diameter steel cords and thicker belt cover, because of high belt rating and hard rock handling. Short idler spacing is usually specified to limit idler load and bearing size. For these conveyors, the IJPI is normally expected to be within design limits, until the belt becomes thin from significant cover wear. The fourth category is very high tonnage conveyors beyond 15000 T/H. This type of conveyor can be found in large stockyards in bulk material handling ports or surface mining operations. These conveyors don't normally have long lengths or a high incline/decline angle, but they are characterized by wide belt and very high tonnage. The IJPI can increase very quickly with a normal three roll trough even with reduced idler spacing. Careful consideration of idler spacing and trough arrangement should be taken to limit the idler junction bending.

Accelerated Cover Wear from Sliding Friction and High Normal and Shear Stress

In Figure 1, the idler contact area shows high deformation areas (red dots) which are under individual steel cords. The contact pressure is relaxed under the rubber gap between adjacent steel cords. Also the contact pressure near the edge of the wing roll and center roll is higher than the rest. Combining the two effects, the localized contact stress can be significantly higher than the average contact stress over the entire contact area.

The contact stress is composed of shear and normal stress. The shear stress is from indentation rolling resistance. The normal stress is from the belt and material weight. In addition, convex curves, whether created intentionally to change the belt direction or unintentionally by idler misalignment, apply part of the belt tension as a vertical load on the idler to further increase the normal contact stress and deformation. For a typical three roll trough configuration, the pressure on the center idler roll is higher than the wing roll.

High normal and shear stress can potentially cause accelerated belt cover wear. One example is shown in Figure 7. This particular belt is traveling at a high speed with heavy material load, so both normal and shear contact stress is high. The contact stress further increases around the idler edges and directly under individual steel cords. In Figure 7, the spacing of the circular damage spots matches the spacing of steel cords in belt, which is exactly the high stress area. If the bottom cover rubber's mechanical property is not strong enough to withstand the stress or strain level, premature bottom cover belt failure will occur.



Figure 7. Bottom Cover Damage at High Contact Pressure Area

The forward tilting of an idler arrangement is adopted as a solution or precaution against belt mistracking. The rotational velocity of a tilted wing roll is at an angle (tilt angle) against the belt travel direction. The linear velocity of a wing roll can be decomposed into two components: one parallel to the belt travel, and the other normal to the belt travel. The velocity component parallel to the belt travel is a rolling contact, which has very minimal wear on the belt. The velocity component, normal to the belt travel direction, is a sliding contact. The sliding frictional force pushes the belt down and stabilizes it. But the sliding friction also creates additional wear on the belt bottom cover in the wing roll contact area. By the same argument, backward tilting is not used because the direction of the frictional force is pulling the belt upward from both wing rolls, which leads to more belt mistracking. Figure 8 shows the belt cover wear caused by the forward tilting of the wing roll. The forward tilting of wing rolls can wear the belt bottom cover down to the steel cords. The high wear area also corresponds to the high contact stress area on the wing roll near the idler junction. For short plant conveyors, belt cycle time is short and the belt top cover tends to wear very quickly. If belt mistracking creates frequent unplanned shutdown of a conveyor, it is reasonable to use the forward tilting of idler wing rolls to improve belt tracking. However such practice should be avoided for overland conveyors, when belt

mistracking should be prevented by proper idler arrangement and good installation accuracy.



Figure 8. Belt Cover Wear Due to Idler Forward Tilt

Cover Damage from Ceramic Pulley Lagging

Ceramic pulley laggings are chosen for their superior wear resistance and higher friction coefficient over rubber pulley laggings. Manufacturers provide different types of ceramic lagging tile designs. Certain ceramic lagging is designed to provide a greater friction coefficient between the belt and pulley, usually by introducing small, sharp edged protrusions on the lagging surface. The protrusions are intended to penetrate into the belt bottom cover and provide greater resistance against the slipping motion of the belt. However, from analysis of classical contact mechanics (5), it is known that on a drive pulley, certain slipping is intrinsic to the interaction between belt and pulley. Aggressive ceramic lagging design, in combination with high tension ratio on a drive pulley, can potentially cause premature belt cover failure. Figure 9 shows the wear marks on the belt bottom cover produced from ceramic lagging tiles, where the spacing of the white stripes (wear marks) match exactly the spacing of the ceramic lagging tiles. Ceramic lagging tile design affects the

contact stress. Figure 10 shows two different ceramic lagging tiles: the left lagging tile has sharp protrusions and the right lagging tile has a wavy surface. Under the same contact condition (belt tension and pulley diameter), the contact stress is more than four times higher on the lagging tiles with sharp protrusions. Indeed the higher contact stress can provide more 'grip' between the belt and pulley, but it can also add to the possibility of belt cover damage.



Figure 9. Belt Cover Wear From Sharp Ceramic Lagging Tile. The lagged pulley surface is shown in the upper left corner.

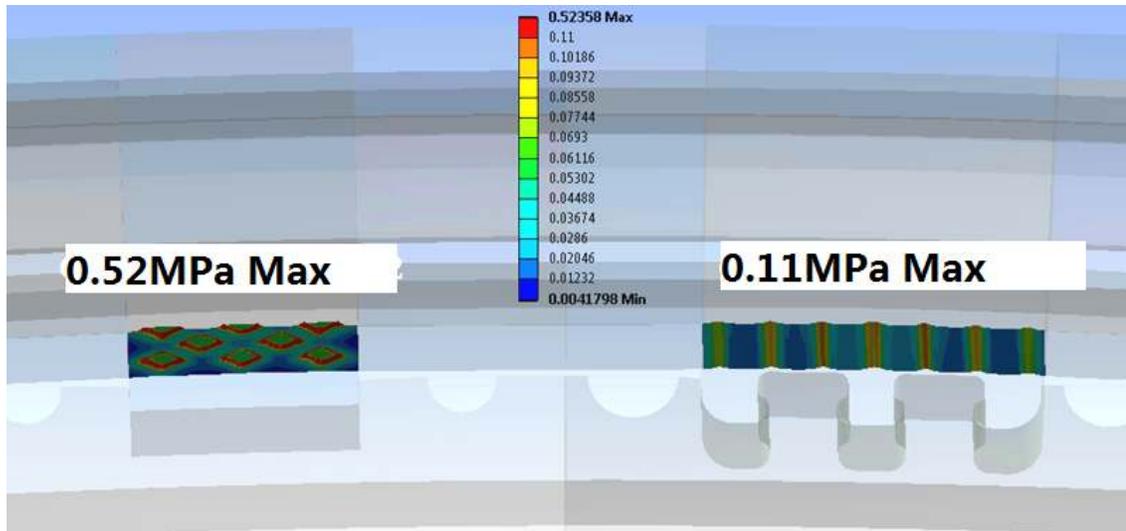


Figure 10. Comparison of Contact Stress between Two Ceramic Lagging Tile Designs

Ceramic lagging tiles may dislodge from the pulley. Missing laggings create an irregular pulley surface. Sharp corners and edges of existing lagging tiles that are adjacent to the missing pieces, are exposed to contact the belt cover and lead to accelerated wear. Figure 11 shows such an example: the belt cover has a wear zone near the center of the belt down to the steel cords, the location of which matches that of the missing lagging tiles on the pulley surface. Although a few missing lagging tiles may seem inconsequential, the related belt damage may quickly escalate to a serious level in which the whole belt needs to be replaced. Good inspection and maintenance practices are essential in preventing such belt damage.



Figure 11. Bottom Cover Wear From Ceramic Lagging

Conclusion

Premature belt bottom cover failure is caused by improper contact behavior between the belt and idlers or pulleys. The physical properties of cover rubber can certainly be enhanced to reduce cover wear, but good engineering and maintenance practices are also essential to prevent accelerated bottom cover wear.

The idler junction failure is caused by excessive bending at the idler junction area, or direct contact with the idler edge. The idler junction bending is related to conveyor and belt parameters: trough angle, belt thickness, material cross sectional loading, idler spacing, material surcharge angle, vertical curves, and idler configuration. The idler junction pressure index indicates whether the idler junction bending has become excessive.

High normal stress from heavy load and convex curves, and high shear stress from high rolling resistance and belt speed can lead to early cover failure, especially near the boundaries of the contact area on wing rolls and center roll, where the contact stress is maximal. A forward tilting idler roll accelerates the cover wear by introducing sliding friction between the belt and wing rolls.

Ceramic lagging tiles with sharp protrusions can cause local high contact stress and increase bottom cover wear. Good maintenance is required to discover and fix missing ceramic lagging tiles on the pulley surface to prevent belt cover damage.

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