Predicting The Life Of Rubber Covered Conveyor Belting

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Summary

Rubber covered conveyor belting has been in use since the mid 19th century. However, the cost of rubber prohibited its wide spread use on conveyor belting until about 1920 when natural rubber became more readily available thereby driving the price down. So that, although rubber covered belts have now been in widespread use for more than 80 years there is still very limited reliable information available for predicting the life that can be expected. Many manufacturer's of rubber conveyor belting have developed there own formulae for calculating belt wear life. Even in the few instances that conveyor belts have actually worn out these formulae have proven to be inaccurate. This paper attempts to throw some light on the reasons why this should be the case. The various factors that effect wear on conveyor belting with rubber covers are discussed and case studies that draw attention to these factors are cited.

Belt life prediction formula

In 1969 BTR Belting supplied the conveyor belting for the Tarbela dam project. It was the intention that the belting supplied should last the lifetime of the project requiring the transfer of all the aggregate from the quarry to build the dam wall. The belt life expectation was not realised. This event led to a study of the wear that took place over time on a number of different conveyors at two sites, one handling crushed stone of 300 mm lump size and down while the other was a mixture of overburden and soil.

A wear life formula was developed from the results of these studies. It was found that the number of tons of material conveyed to wear 1 mm of cover was directly proportional to the cycle time and the full cross sectional load area. Thus, values could be derived from the measured results for the number of tons that would wear 1 mm of top cover for a standard cycle time of 60 seconds. These values are given in table 1 for material of bulk density equal to 1500 kg/m^3 and a belt speed of 5 m/s.

It was postulated that, all other things being equal, the tonnage that will be conveyed to wear a unit thickness of cover is directly proportional to the relative density of the material and the relative abrasion resistance of the cover and inversely proportional to the relative belt speed. It was also assumed that each unit of cover thickness would wear at an equal rate.

$$W_l = \frac{T_f \cdot D \cdot C_t \cdot A \cdot t}{S} \qquad (1)$$

where W_l = Wear life (Mt)
T_f = million tons conveyed to wear 1 mm of cover for 60 second cycle
D = relative density of material conveyed
C_t = cycle time (minutes)
A = relative abrasion resistance of belt cover material
t = cover thickness (mm)
S = belt speed

The approximate cycle time is given by

$$C_t = \frac{2L}{60S} \qquad (2)$$

where L = conveyor length (m)

Substituting for C_t, formula (1) can be rewritten as follows:

$$W_l = \frac{T_f \cdot D \cdot A \cdot L \cdot t}{30S^2} \tag{3}$$

Belt Width (mm)	Quantity of material to wear 1 mm of cover (Mt)
750	0.50
900	0.75
1050	1.10
1200	1.35
1350	1.85
1500	2.30
1800	3.35
2100	4.55

Table 1 T_f **(tonnage factor)** tonnage to wear 1 mm of cover for a 60 second belt cycle time, material bulk density of 1500 kg/m^3 and a belt speed of 5 m/s.

Faster than predicted cover wear rate

In a number of instances conveyor belts have worn out rather than being replaced due to some form of damage. Certain of these conveyor belts wore considerably faster than predicted by application of formula (3). Study of the conveyor feed arrangements highlighted a number of other factors that are not accounted for in the wear life formula above. Most important of these factors are the angle at which the material strikes the belt, the vertical velocity of the material, turbulence in the material feed, belt modulus, arrangement of idlers at the loading point and the characteristics of the material.

The mechanics of wear

Rubber compounds differ considerably in make up and consequently in physical properties. The most important measures of the quality of conveyor cover rubber are the tensile strength and tear strength. A number of other physical characteristics have an important bearing on the ability of the rubber cover to provide a long wear life. Of these ‘other characteristics’ the most important are probably the abrasion resistance and cut resistance. There is a general belief that a rubber compound with high abrasion resistance should return the best belt life. However, consideration of the abrasion resistance of a rubber compound in isolation is misleading. The test to measure abrasion resistance measures only pure sliding abrasion. It is possible to formulate rubber compounds with abrasion loss of as low as 50 or 60 mm^3 yet the best rubber compounds used in conveyor belting have an abrasion loss of 90 to 120 mm^3. The reason for this is that the rubber compounds that have exceptionally low abrasion loss do not have high tensile strength or tear strength. Good quality rubber for conveyor belting is characterised by a high tensile strength and high tear strength. These afford the rubber an ability to deflect under load without ill effect.

When an individual particle (lump) of material moves across the belt surface it is possible that some degree of damage will occur to either the belt or the material particle or both. In this paper focus is concentrated on the damage to the belt surface. The pressure exerted by the particle relative to the belt, characteristics of the particle, physical properties of the belt and the angle of impingement dictates what happens to the belt surface when they make contact.

Angle of impingement of material on the belt

Field studies undertaken by Trelleborg showed that the wear rate of rubber components was very dependent on the impingement angle. Using high strength soft rubber as a lining medium on a conveyor discharge chute Trelleborg were able to correlate the rate of wear to the angle of incidence of the stream of discharged product onto the lining. Figure 1 shows the relationship between rate of wear and angle of impingement that was obtained in these studies. It was shown that, for the particular rubber used as a lining material, the critical angle was 22° and the lowest rate of wear occurred at an angle of 90°.

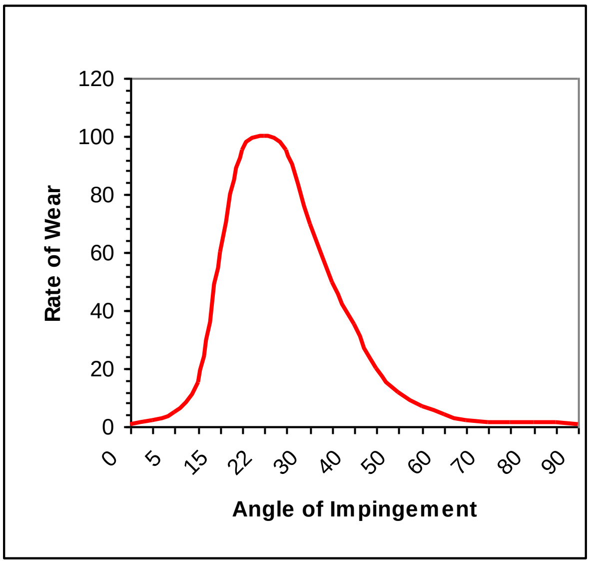

Figure 1 Rate of Wear of Soft Rubber Lining vs Angle of Impingement

Data gathered from a number of conveyors showed that the wear rate of the conveyor cover is also related to the angle at which the material makes contact with the cover. Conveyor belting covers are made with harder rubber compound than that used for lining and as a consequence the increase in the wear rate is not as pronounced as that for lining material, as depicted in figure 2.

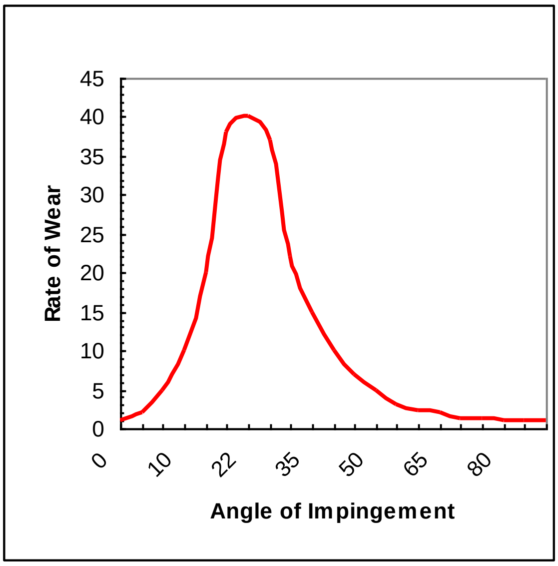

Figure 2 Rate of Wear of Rubber Cover vs Angle of Impingement

Thickness of cover versus rate of wear

The ability of rubber to deform under load gives it the exceptional wear resistance characteristics. As the rubber thickness decreases the ability to deflect diminishes. Thus, as the rubber thickness is reduced by wear, or indeed if the initial thickness is insufficient its rate of wear increases. Steel cord reinforced conveyor belting has zones of unequal cover thickness. Immediately above each cord the cover thickness is minimised while between individual cords the cover thickness is equal to the belt thickness. As the cover wears a point is reached where the wear rate increases in the zones above the steel cords and a wear pattern depicted in figure 3 develops. There is a minimum thickness required to provide sufficient resistance to wear. Empirical data has been gathered for the minimum thickness required for a range of material densities and material lump size. This is given in table 2. The amount of wearable cover is taken to be the actual cover thickness less the minimum thickness necessary.

Lump Size (mm)	Material Density (kg/m^3)		
	800	1600	2400
> 300	1.7	3.5	5.2
150 – 300	1.5	3.0	4.5
100 - 150	1.2	2.5	3.7
50 – 100	1.0	2.0	3.0
20 - 50	0.6	1.5	2.4
< 20	0.5	1.0	1.5

Table 2 Minimum required cover thickness

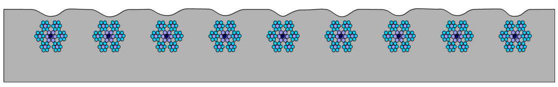

Figure 3. Wear pattern that develops in steel cord reinforced conveyor belting

Width utilisation

When the full available belt width is utilised to convey the material the belt wear rate is minimised since the wear is distributed over a wider surface. This situation is best when the exit width of the loading chute is also at maximum. The converse holds when a small load capacity relative to the available belt width is conveyed and made even worse when a very narrow stream of material is loaded. The later is immediately obvious since the material makes contact with the belt over a very narrow width and all wear is concentrated at this point. The absolute worst case exists when not only is the material stream vary narrow but also very shallow. No worse situation exists than when the material stream depth is the same as the material lump size. Every lump of material makes contact with the belt. Potentially the percentage of material that makes contact with the belt can be reduced to the ratio between the loaded width of belt and the material cross section. Thus the wear situation is worse for lightly loaded belts than those that are loaded to near the maximum possible capacity. It therefore makes sense, from a wear point of view, to reduce the belt speed when lighter loads are being conveyed.

Material turbulence at the loading point

Material turbulence is the situation in which individual lumps of material have different velocities. Whereas the material stream being fed to the belt may have no turbulence, if the material velocity is different to the belt velocity, turbulence is always induced. The degree of turbulence induced is related to the velocity difference and the material characteristics. Very free flowing material having a higher degree of turbulence imparted than more sluggish material. When the material stream has an open configuration turbulence is more likely since individual particles are less influenced by those surrounding it.

A great amount of turbulence at the load point results in an increase in the number of material lumps making contact with the belt and therefore an increase in the rate of wear.

It is possible to predict the velocity of material flow through a chute and therefore the angle that the material flow has relative to the belt can be determined. Material that tumbles through the chute does not allow any specific alignment of the individual lumps. In such cases the angle at which the material strikes the belt is calculated by consideration of material stream velocity relative to the belt.

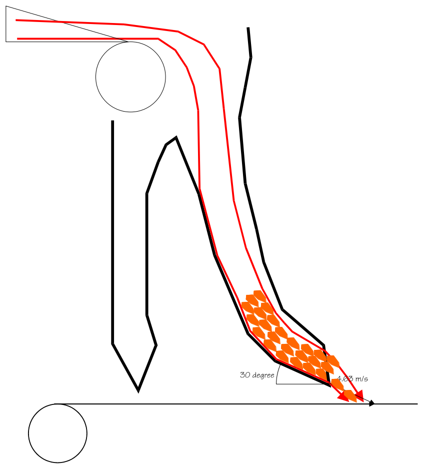

Figure 4 Smooth flow through the chute aligns slab material

However, the individual particles in the stream have an angle of impingement that can be influenced by the particle shape and alignment. For example, predominantly rectangular shaped lumps of material would tend to be aligned longitudinally when flowing smoothly along a load chute and would then be introduced to the belt as depicted in figure 4. In such a situation the effective angle of impingement with the belt is not influenced by the velocity difference but is approximately equal to the chute angle at the discharge point. Exactly such a situation resulted in very rapid cover wear occurring after a load chute had been changed. The new load chute providing improved material throughput and virtually no tumbling of material but aligning the sharp slabs of material at a very unfavourable angle of 30° to the belt.

Modulus of the conveyor belt

A belt with a high modulus requires a relatively large force to be deflected. So, when a load is introduced to belts having a high modulus the rubber cover must absorb all the instantaneous pressure. Conversely, a belt with a low modulus will deflect by a relatively large amount when the same load falls onto it. The belt cover will therefore need to absorb far less of the material's instantaneous pressure.

Spacing of the idlers at the loading point

Good conveyor design has always dictated that the idler spacing be reduced at the loading point. This design philosophy is good from a point of view of reducing spillage and reducing the impact forces transferred to individual idler rolls but from a belt wear point of view is a disaster. The sag (deflection) resulting from a given force on the belt is proportional to the square of the idler spacing and thus the amount of instantaneous pressure that must be absorbed by the belt cover is proportional to the inverse of the idler spacing squared. Ideal idler configuration at the load point is depicted in figure 5. In the diagram, the belt has been 'cut away' to show detail of the load chute arrangement. The idlers within the load area are

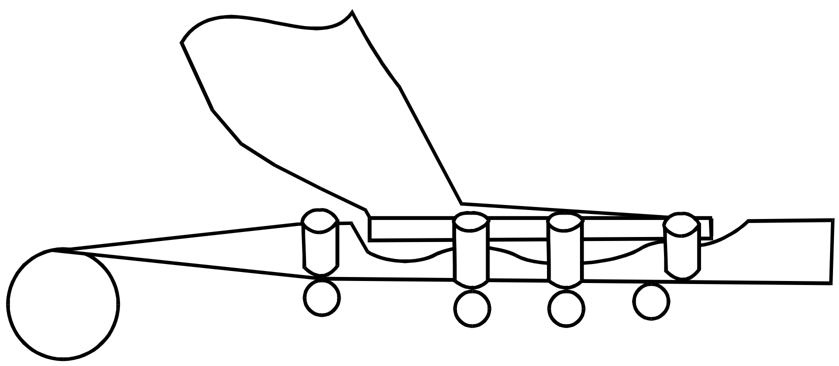

Figure 5 Layout of Idlers in the Load Area

either set lower than normal or garland type impact idlers are used. To ensure that the belt edges are held in contact with the skirtboards the troughing angle of the idlers in the loading area should be greater than the supporting idlers before and after the load area.

A new wear life formula

Using all of the available knowledge an improved method of predicting a belt life can be developed.

The table of rates of wear for material of 1500 kg/m^3 density (table 1) is the base. These values are corrected to a density of 1000 kg/m^3 and the table made more complete by introducing additional widths and additional data for general feed conditions. The modified table of tons that will wear 1 mm of cover at a 60 second cycle (table 3) therefore includes good and poor feed chute arrangements. The average being derived directly from table 1 corrected to 1000 kg/m^3 and a belt speed of 1 m/s. Good conditions prevail when the full capacity of the belt is utilised, the material has minimal turbulence and minimal vertical velocity. Poor conditions exist when none of these criteria are met and average conditions when only partly met.

Belt Width (mm)	Feed Conditions			Belt Width (mm)	Feed Conditions		
	Good	Average	Poor		Good	Average	Poor
600	1.65	1.00	0.37	1500	12.01	7.20	2.67
750	2.72	1.63	0.60	1650	14.65	8.79	3.26
900	4.05	2.43	0.90	1800	17.56	10.54	3.90
1050	5.64	3.39	1.25	2100	24.18	14.51	5.37

1200	7.50	4.50	1.67	2200	26.62	15.97	5.91
1350	9.62	5.77	2.14	2400	31.84	19.11	7.08

Table 3 Tonnage factor T_f

$$W_l = \frac{T_f \cdot D \cdot A \cdot L \cdot t_w \cdot C_\theta}{30S^2} \qquad (4)$$

where
T_f = tonnage factor from table 3
D = relative density of the material
A = abrasion factor for rubber cover
L = conveyor length (m)
t_w = thickness of wearable cover (mm)
C_θ = angle correction factor
S = belt speed (m/s)

Thickness of wearable cover is obtained by subtracting the minimum required cover thickness in table 2 from the actual top cover thickness.

Angle correction factor is the inverse of the wear rate read from the graph shown in figure 2 for the angle at which the material strikes the belt.

Optimum cover thickness

The formula to calculate the number of tons that will be conveyed before the belt has worn can be modified to determine the amount of wearable cover necessary to convey a desired capacity. The wearable cover thickness is then converted to the required cover thickness by adding a value from table 2. However, certain other considerations may dictate that a thinner cover and in consequence a shorter life expectancy is more prudent. The most obvious consideration is an expectation that an event will occur that will cause irrepairable damage to the belt. Based on history of such events at a particular site the frequency factor for these events should be taken into cognisance in determining the desired capacity to be conveyed by the belt. It should be born in mind that increasing the thickness of rubber increases the belts resistance to ripping and tearing so that the cover thickness should never be reduced when belt rips are the primary reason for replacing a belt.

There is a limit to the number of cycles that a belt carcass will execute. Multiply belt carcasses generally have a shorter life expectancy than those with a single plane of reinforcement, such as a cord construction. The greater the number of plies, the fewer flex cycles that can be expected before fatigue reduces the carcass life expectancy. Multiply construction design is centred on a 4 ply construction. A specific belt fabric design would be accepted if, when used in a 4 ply carcass, it is able to withstand 100000 flex cycles without fatigue. Fatigue would generally result in delamination of the plies and/or to a reduction in the whole belt breaking strength. The flex test is not a standard test in any belting specification and therefore belting manufacturers have different methods of test. The relationship between the test procedure and the fatigue life of the belt in service is not necessarily correlated since the tests compress the time between cycles. A general rule of thumb is that the number of cycles that can be achieved in service is 2.5 times the number of cycles achieved in a footwear flex testing apparatus. Thus a belt carcass that can withstand 100000 cycles on a footwear flex test apparatus would achieve 250000 cycles in service. Since more than 90% of belts are replaced before 250000 cycles are achieved there is not an abundance of data to scientifically verify these figures. Rubber covered conveyor belt top cover thickness should therefore not be selected for more than 250000 belt cycles.

Rubber has a limiting age of about 15 to 30 years when conveying material of ambient temperature. Keeping rubber 'active' improves the aging life. Thus the portions of the rubber covered conveyor belt surface that are continuously subjected to the load will age more slowly than those that are not. Rubber will also age more rapidly when under tension. Therefore, the most rapidly aging portion of a rubber covered conveyor belt are generally the zones of bottom cover coinciding with the trough idler junction points. These zones spend half their operating time under tension and are normally never subjected to wear. The limiting age for selecting of the top cover thickness should be of the order of 15 years.

Short comings of the wear life formula

It will be noted that no mention of the material characteristics, particularly sharpness and abrasiveness, is made. In applying formula 4 to an application conveying abraded iron ore and one conveying freshly crushed iron ore with very sharp surfaces, the results would be the same. Intuitively one feels that different results will be achieved in practice. A practical solution to this problem is to create new tables of tonnage factors based on actual records of wear.

Example of Predicting Belt Life

An actual conveyor carrying iron of bulk density between 2.5 and 3.3 t/m^3 was investigated for rate of wear of the top cover. The conveyor was fitted with steel cord reinforced belting having a top cover thickness of 6 mm. The conveyor length was 1730 m and the belt speed 3.8 m/s.

Using the original BTR belt life formula.

From table 1 the tonnage factor is 0.75 for a 900 mm wide belt. The lower ralative density of 2.5 will be used for the most conservative estimate of belt life. Assume that the abrasion resistance of the cover is the same as that of the belting used in the studies i.e. a relative abrasion resistance of 1. Then the predicted quantity of material that could be conveyed to wear the top cover is

$$\frac{0.75 \times 2.5 \times 1 \times 1730 \times 6}{30 \times 3.8^2}$$

= 45 Mt

Using the improved belt life formula.

The angle of impingement of the material on the belt at the loading point was approximately 45 degrees. From figure 2 the wear rate is 9 and therefore the angular correction factor is 0.111. Although the load chute ensured very low vertical velocity of the material onto the belt and virtually no turbulence, the percentage of full capacity utilised at most times was relatively low and therefore average feed conditions existed. The tonnage factor from table 3 is therefore 2.43. The material lump size was 85 mm. Table 2 lists 3 mm as the minimum required cover thickness and therefore the wearable cover thickness is 3 mm (6 – 3). Substituting in formula 4 the predicted amount of material that could be conveyed is

$$\frac{2.43 \times 2.5 \times 1 \times 1730 \times 3 \times 0.111}{30 \times 3.8^2}$$

= 8 Mt

After conveying 9.4 Mt of material the top cover of the belt fitted to the conveyor in question had worn 4 mm in the centre. The cover had therefore worn beyond its wearable cover thickness as predicted by application of the improved wear life formula.

Example of optimising top cover thickness at design stage

Consider a 1200 mm wide conveyor of 2400 m length carrying overburden of up to 250 mm size and bulk density of 1.6 t/m3. Suppose the belt speed is 2.3 m/s and the design capacity 1800 t/hr. For this exercise a life expectancy of 15 years is to be achieved during which time a total of 75 Mt is to be conveyed. Analysis of the conveyor indicates that the belt will be filled to 80% of maximum capacity and therefore, assuming good chute design, the value listed under good conditions column in table 3 can be used. Assume that the chute can be designed to feed the material onto the belt at a 60° angle.

T_f = 7.5 (table 3)

D = 1.6

A = 1 grade M rubber

L = 2400 m

C_θ = 0.412 inverse of 2.4 (figure 2)

S = 2.3 m/s

For the purposes of determining the amount of wearable top cover required formula 4 is rewritten as follows:

$$t_w = \frac{30W_l \cdot S^2}{T_f \cdot D \cdot A \cdot L \cdot C_\theta} \qquad (5)$$

$$= \frac{30 \times 75 \times 2.3^2}{7.5 \times 1.6 \times 1 \times 2400 \times 0.412}$$

= 1.0 mm

The actual top cover thickness should therefore be 1 + 3 (minimum from table 3) i.e. 4 mm.

Operating 24 hours of every day this conveyor would complete 231882 cycles in 15 years and therefore is not a limiting factor.

Conclusion

The method of predicting the wear life of a rubber covered conveyor belt provides a means of optimising the cover thickness. However, it should not be used as a measure of the quality of the belting. In most instances it will be found that if the belt wears faster than predicted AND good housekeeping has prevailed then the design of the load arrangement is in question. Therefore, it is suggested that the application of the wear life prediction method be used only as follows:

1. To optimise the belt cover thickness in the design stage.
2. As a diagnostic tool to optimise loading arrangements during the life cycle of the conveyor system.