APPLIED BELT SPLICE DESIGN

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There are several standards, like DIN 22131 Part 4, that prescribe a design for a belt splice of a specific belt class. The design normally consists of a prescription of the splice length, the right angle, and the actual layout pattern of plies or cords. There are however, no standards that explain the relationship between the design of a belt splice and the specific application which that splice has to perform. What for example, is the effect of the belt speed; the conveyor length; the relaxation distances between pulleys; the pulley diameter; transition distances; and the conveyor dynamics on the performance of a splice? How does one ensure that belt splices do not jeopardize the safety of a belt conveyor?

This paper discusses the fundamental background of a splice design and explains how the specifics of a certain application may affect the splice design.

1. INTRODUCTION

Conveyor belts are produced in pieces of a certain length and rolled into a roll. This length is determined by the maximum belt roll diameter and/or the maximum allowable transport weight. The average length of belting on a roll is about 300 m. In order to make a belt endless, a splice is required. Since most major belt conveyors need an endless belt longer than 300 m, multiple splices are necessary. A splice is the weakest link in a conveyor belt. In addition, the splice strength is in time reduced by fatigue. To ensure that a belt conveyor operates safely during its intended lifetime, the splice needs to be carefully designed. Splice designs are standardized by standards like DIN 22131 – Part 4 (1). However, a splice is never a 'one size fits all'. This paper therefore describes the fundamentals of splice design that assist in the design of a belt splice which safely operates in a specific application. The focus is on steel cord belts.

When considering a conveyor belt there are two components that determine the technical lifetime of a belt: the condition of the belt covers, in particular the top cover, and the splices. The top cover thickness is chosen so that the anticipated wear over the lifetime of the belt is such that some top cover rubber still remains at the end of the belt's life. Splices need to be designed in such a way that the fatigue life of the splices in the belt exceed the lifetime of the overall belt. The top cover thickness selection is not discussed in this paper.

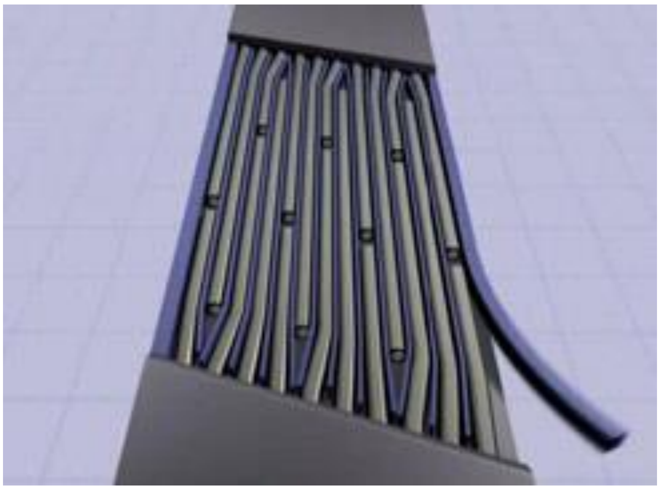

Figure 1. An open steel cord splice

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In a splice, the normal layout of the conveyor belt carcass is discontinued and the end of the one belt is connected with the end of the adjacent belt by means of a splice. Figure 1 shows an open splice of a steel cord belt that illustrates a specific pattern of the splice cables. As can be seen, the cables of both ends are laid in such a pattern that they overlap. In between this cable overlap zone, rubber strips are inserted. These rubber strips, after vulcanization of the splice, allow the transfer of forces arising from the belt tension from one cable to the other. This tension transfer causes shear stress in these rubber strips. Therefore these strips are also called shear panels. In practice, numerous splice patterns are possible, see for example Figure 2.

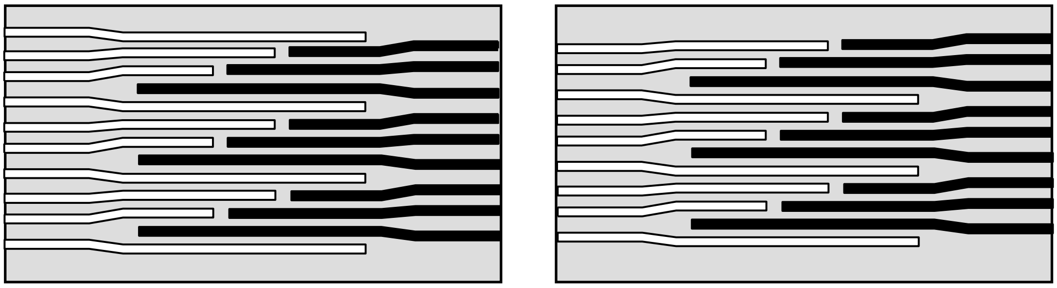

Figure 2. Two options for a steel cord belt splice pattern

2. S-N CURVES

DIN 22131 – Part 4 describes a test that establishes the fatigue strength of a test splice under a continuous varying dynamic load. Using this test, a curve that links the number of load cycles N with the shear stress in the belt splice can be determined. This curve is called the S-N curve. In literature this curve is also called the Wöhler curve. The test conveyor belt with the splice to be tested is positioned around two pulleys (Figure 3). One of the pulleys is able to move and apply a certain tension on the test belt. The diameter of the pulleys depends on the belt rating. The tension is varied in a saw-tooth fashion between limits over a certain period of time. A total tension cycle takes the belt 18 rotations around the test rig. The lower stress level is fixed at 6.67% of the rated braking strength of the installed test belt. The higher tension is changed from test to test and the belt is tested until the splice breaks.

Each test therefore produces a S-N point. With multiple tests, varying the maximum tension, the S-N curve can be made (Figure 4). The tension in the belt produces a shear stress in the splice. The value of the tension at which the splice lasts at least 10,000 cycles is called the fatigue strength of the belt (S_e in Figure 4). The shear stress that corresponds with S_e is called the endurance stress σ_e. A splice that lasts 10,000 load cycles is considered a safe splice.

Figure 3. Test conveyor belt positioned around two pulleys

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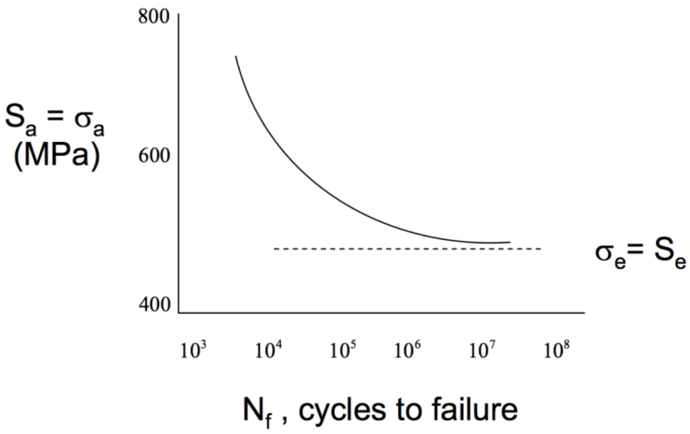

Figure 4. An S-N curve

As said before, the test conveyor belt is subjected to a fluctuating dynamic tension causing a fluctuating dynamic stress in the belt. The maximum stress is σ_{max} and the minimum stress, at a belt tension of 6.67% of the belt's rated braking strength, is σ_{min}. The mean stress σ_m then can be defined as

$$\sigma_m = \frac{\sigma_{max}+\sigma_{min}}{2} \qquad 1$$

The stress amplitude σ_a, also called the alternating stress, is defined as

$$\sigma_a = \frac{\sigma_{max}-\sigma_{min}}{2} \qquad 2$$

Different combinations of the mean stress and the alternating stress can give the same lifetime for a splice. This can be visualized in a so-called constant life diagram, (Figure 5).

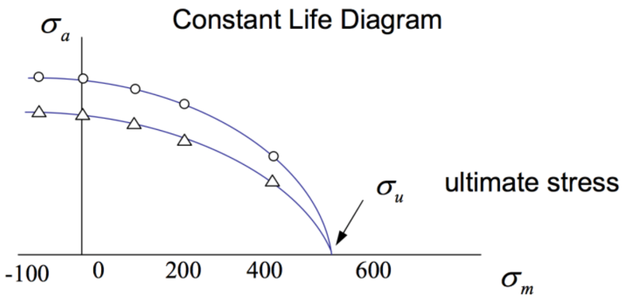

Figure 5. Constant life diagram

The end of the constant life diagram is formed by the belt's rated braking strength or ultimate stress σ_u. The two lines in Figure 5 indicate two different levels of live or in this case N. The line to use here is the line that represents N=10,000. That line indicates the difference between a safe combination of the mean stress and the alternating stress and an unsafe combination, also see Figure 6.

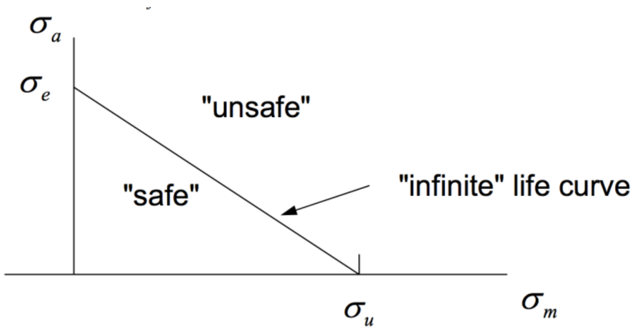

Figure 6. Safe and unsafe zones in the life diagram

In literature [2] two approximations of the constant life curve are used. The first is the approximation of Goodman (England, 1899)

$$\frac{\sigma_a}{\sigma_e'} + \frac{\sigma_m}{\sigma_u} = 1 \qquad 3$$

The second approximation is Gerber's (Germany, 1874) approximation

$$\frac{\sigma_a}{\sigma_e'} + \left(\frac{\sigma_m}{\sigma_u}\right)^2 = 1 \qquad 4$$

In practice the constant life curves tend to fall between the Goodman and Gerber curves. The life curves can be used to access whether a combination of alternating stress and mean stress leads to a safe operation of a belt conveyor with that specific splice design.

Instead of testing a full steel cord belt splice, as specified by DIN 22131 – Part 4, an 'H-block' can be used in combination with the finite element method. Figure 7 shows an H-block that is a block of vulcanized rubber normally with three steel cords. Variants with five cables are also used. The steel cords are the same cords as the steel cords used in the steel cord belt. The rubber of the H-block is the same rubber as the rubber used in the splice of the belt.

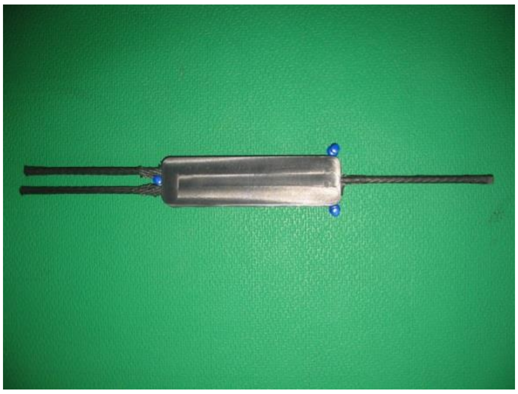

Figure 7. H-block

An H-block is designed in such a way that the shear stresses that normally occur in the envisioned total splice also occur in the H-block. Therefore the overlapping lengths of the steel cords in the H-block as well as the pitch between the cables need to be carefully selected. Using a series of H-blocks and a tensile tester that is used to subject the H-block to a dynamic load curve enables the determination of the S-N curve of the H-block (with tension and not shear stress). Since the tensile tester applies a force on the cables of the H-block, this force needs to be translated to a shear stress in the shear panels between the steel cords. For this a finite element model of the H-block can be used, (Figure 8). Therefore the combination of the finite element model of the H-block and the results of the tensile tests produce a true S-N curve linking shear stress to number of load cycle N. This S-N curve is also valid for the total splice as long as the maximum stress in the total splice remains less than the endurance stress determined with the H-block. For the design of the total splice, a finite element model of the total splice needs to be made. The advantage of the test procedure with H-blocks and finite element models versus a total splice test is that the H-block procedure is much faster and cheaper as it enables virtual prototyping. The disadvantage is that some end users of conveyor belts do not accept the procedure.

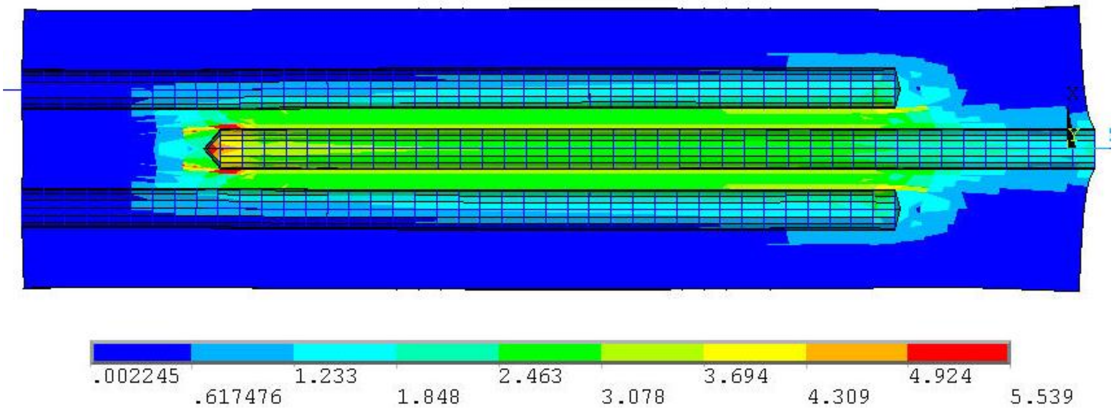

Figure 8. Finite element model of an H-block

3. FLUCTUATING STRESS

In the previous paragraph it was assumed that a splice is subject to a constant average stress and a fixed alternating stress. In reality this is, of course, not the case. In reality the belt tension depends on the load and operational conditions. In other words, it makes a difference to the belt tension whether a belt is empty or fully loaded, whether it is summer or winter, and whether the belt is running at a constant speed or starting/stopping. In order to take into account the load variations, which lead to stress variations, a cumulative load diagram is essential. A cumulative load diagram graphically presents all the loads acting on the belt during its lifetime.

Assume that a belt conveyor makes N revolutions or load cycles in its lifetime. During N_1 cycles the maximum stress is σ_1, during N_2 cycles the maximum stress is σ_2 etc. The maximum stress used in the splice design calculations then is (2)

$$\sigma_{max} = \sqrt[3]{\frac{\sigma_1^3 N_1 + \sigma_2^3 N_2 + \sigma_3^3 N_3 + \cdots}{N}} \qquad 5$$

4. APPLICATION FACTORS

In Paragraph 3 the dependency of the stress on the load factor and the operational conditions was mentioned. Here, the impact of various belt conveyor design choices on the life of a splice are discussed.

4.1 Belt speed

An important belt conveyor design choice is the belt speed. Depending on the nature of the bulk solid material to be transported and on the length and application of the belt conveyor, a belt speed is selected. Normally, a rule of thumb can be used: fine materials use a low belt speed, course materials a high belt speed, in-plant conveyors run at a low speed whereas overland conveyors use a higher speed.

Given a specific belt conveyor's length L and belt speed v, the number of load cycles the conveyor belt completes per year is

$$N_{year} = 15{,}768{,}000 \frac{v}{L} \quad (6)$$

From Equation 6 it is learned that if the belt speed doubles, the number of load cycles doubles as well. If the lifetime of a splice, and thus the conveyor belt, is guaranteed for a certain number of years, which is not uncommon, then with an increase in belt speed, an increase in fatigue life is required. In practice this means that a conveyor belt with a higher belt speed needs a longer splice to reduce the maximum shear stress and thus increase the number of load cycles until the end of the belt's lifetime.

4.2 Conveyor length

The belt length has the opposite effect on the lifetime of the belt when compared to the belt speed. The longer the belt conveyor, the fewer load cycles the conveyor belt makes over a given period of time (Equation 6). This means that generally, with an increase in the length of a belt conveyor, the length of the splice can decrease because fewer load cycles allow for a higher maximum shear stress. In practice this is relevant because it means that long overland conveyors may require shorter splices than the splice length prescribed by standards like DIN 22131. This leads to a reduction in splicing time and costs.

4.3 Relaxation distance between driven pulleys

After a belt splice passes a driven pulley the belt needs to 'recover' from the sudden change in tension. The belt tension and thus stress before the driven pulley is higher than after the driven pulley unless the system is regenerative. The belt needs time to relax from the change in tension and the elongation that follows. If the belt does not have the opportunity to relax before it passes the next driven pulley, as in the case in multiple driven pulleys, then a residual stress remains in the belt, which increases the overall stress in the belt. This needs to be accounted for in the compilation of a cumulative load diagram.

4.4 Pulley diameter

The pulley diameter determines the extra bending stress in the belt. When passing a pulley the extra stress in the belt is equal to

$$\epsilon_p = \frac{\Delta l}{l} = \frac{2t}{D} \quad (7)$$

where t is the belt thickness and D the pulley diameter.

In general it can be said that with an increase of the pulley diameter, a belt stress reduction can be achieved. This effect also has to be taken into account in the cumulative load diagram. However, the impact of the pulley diameter on the splice design is limited.

4.5 Transition distances

Similar to the discussion on the pulley diameter, the transition from a flat belt to a troughed belt imposes an additional stress into the belt. This extra stress depends primarily on the transition length, the belt width, the trough angle and the length of the wing rolls. Usually, an increase in transition length leads to a decrease in belt stress. The impact of the transition length on the splice design however, like the pulley diameter, is limited.

4.6 Dynamic conditions

An important factor in the splice design is the maximum dynamic belt tension. Normally the maximum belt tension, and thus stress, occurs during start-up of a belt conveyor. Therefore the start-up procedure, characterized in start-up profile and time, and the number of starts during a day determine the impact on the belt stress. The maximum belt tension during start-ups has to be incorporated in the cumulative load diagram. To determine the dynamic belt stresses, a dynamic analysis is required. In general it can be said that a decrease of the start-up time increases the belt stress. Therefore an appropriate start-up time needs to be determined (Equation 3).

6. CONCLUSIONS

The previous paragraphs describe how an applied splice design procedure can be set-up to enable the safe operation of a belt conveyor. The first step is to determine the belt tensions and stresses. To achieve this, a static design procedure must be followed to determine the belt stresses during steady state running under the different load cases (empty versus fully loaded). At the same time extra stresses from, for example, the pulleys and transition distances are taken into account. Secondly a dynamic tension analysis is performed revealing the belt stresses during the different operational conditions (starting and stopping). When the different belt stresses have been determined and the relative time that the belt is subjected to these stresses, the cumulative load diagram is created.

Using Equation 5, the maximum stress to use in the splice design is calculated. Using the information from the S-N curve, for which H-block tests are required, a proper splice design can be made by using the finite element method as demonstrated in this paper.

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