Influence of Natural Aging Processes in Steel Cord Conveyor Belt on Adhesion Between Core and Covers

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Abstract The paper presents the results of tests on the changes in adhesion strength of the rubber covers to the core of a conveyor belt type St 3150. The investigations focused on four conveyor belts from the same manufacturer, produced in 1987, 1998, 2007 and 2016. The tests demonstrated that the values of adhesive strength decreased with time. The decrease of this parameter was caused by the natural aging of belts operated in a mine and therefore exposed to various atmospheric factors such as variable ambient temperature, snow, rain and solar radiation. The results of adhesion strength tests of the cover to the steel cord served to evaluate the usefulness of such belt in further operation on belt conveyors. The evaluation was made with regard to the admissible values for belts operated in a mine.

1. Introduction

Steel cord conveyor belts represent the most frequently used type of belts in Polish mining industry and typically comprise two elements: the core and the covers. Loads in this type of belts are carried by the belt core which is constructed of steel ropes connected with core rubber. The core has a decisive impact on belt technical parameters, such as tensile strength and elongation. The primary function of the rubber covers is to protect the core. The rubber compositions used in the covers are modified to meet the requirements of the users [1]. These requirements typically include increased resistances to abrasion, tears, cuts, high temperatures and oils, as well as flame retardation. The main advantages of steel cord conveyor belts consist in high tensile strength, which can reach 10 000 kN/m, and in limited relative elongation. As a result, belts with steel core may be used in long and high-capacity conveyors which transport material over distances of up to 30 km.

During its operation, the belt is subjected to a number of factors which may lead to its severe damage [2, 3]. Therefore, apart from adequate strength parameters, it should also demonstrate high resistance to wear and tear, e.g. abrasion, punctures and longitudinal cuts, as well as to atmospheric conditions. Belt manufacturers make continuous efforts to improve belt parameters. The purpose is to increase belt life. Currently manufacturers provide their belts with warranties between 3 and 6 years. Frequent monitoring of belt condition and careful maintenance allow performing necessary repairs in due time to prevent defects from developing [4, 5]. Such measures increase belt life up to above 10 years, resulting in significant financial savings. On occasions, belt repairs consist solely in the filling of small-scale rubber losses. However, repairs may also require cutting a belt fragment and replacing it with a new fragment. For this reason, mining companies avoid buying new belts and instead make attempts to fully use all of the belts at their disposal, even those which have been stored in a mine for a long time. Therefore, research should focus on the influence of natural aging on belt strength
parameters [6, 7, 8]. This influence was evaluated by testing the adhesion of the covers to the belt core.

2. The tested objects
The tests were performed on four steel-cord belts type ST 3150, manufactured in 1987, 1998, 2007 and 2016 by the same producer. The belts manufactured in 1987, 1998 and 2007 were operated on the conveyor for 3 to 5 years. After this period, the belts were no longer operated and were stored in a stacking yard in the mine. Belts of this type are used to transport mined material over long distances (exceeding 500 m) and on routes in which conveyor inclination angle reaches 23° [9]. They prove useful in long-distance transportation as they have relatively small elongation and high strength. Moreover, owing to their high transverse flexibility, the troughing angle may be even up to 70°.

Table 1 shows basic design parameters of the tested belts. As compared to the other belts, the belt manufactured in 2016 is wider and has a higher number of steel cords in the core.

| Year of production | Belt width, mm | Number of cords | Cord pitch, mm | Thickness, mm | Rubber hardness, ShA |
|--------------------|----------------|-----------------|----------------|--------------|---------------------|
| 2016               | 2247           | 146             | 15.0           | 27.5         | 7.3 71             |
| 2007               | 1760           | 116             | 14.7           | 27.6         | 7.6 71             |
| 1998               | 1890           | 116             | 15.9           | 24.9         | 5.8 68             |
| 1987               | 1780           | 116             | 14.7           | 24.2         | 6.4 68             |

Table 2 presents the values of tensile strength and elongation at break of the carrying cover and the pulley cover. It also includes adhesion values of the steel cord to the core rubber. The parameters were determined in laboratory tests performed in accordance with international standards.

| Year of production | Tensile strength, N/mm² | Elongation at tear, % | Adhesion of the cord to the core rubber, N/mm |
|--------------------|--------------------------|-----------------------|---------------------------------------------|
| 2016               | 25.5/24.9                | 595/597               | 210.7                                       |
| 2007               | 25.3/23.6                | 586/529               | 191.6                                       |
| 1998               | 24.5/22.1                | 540/521               | 148.9                                       |
| 1987               | 22.0/20.6                | 464/490               | 129.2                                       |

3. Laboratory tests of adhesion between the covers and the belt core
One of the most frequently performed tests of steel cord conveyor belts is aimed at identifying adhesion strength of the covers to the belt core. Exceeding adhesion limit values may result in the delamination of the covers from the belt core when the conveyor is in operation. The cord in the core may then become exposed and, under the influence of atmospheric conditions, undergo degradation processes. As a consequence, the conveyor belt may even be broken.

3.1 Test method
The adhesion test of the covers to the belt core was performed in accordance with the method described in [10]. The method consists in determining the force required to delaminate the covers from the belt core. To this end, the sample is placed in the jaws of the INSTRON testing machine (figure 1) and stretched with a constant speed of 100 mm/min, causing delamination along at least 100 mm of the belt length.
The tests were performed on belt samples 250 mm in length and 25±0.5 mm in thickness. Each belt provided 6 samples – 3 for adhesion tests on the carrying cover side and 3 for adhesion tests on the pulley cover side. The samples were cut in parallel to the belt axis – two samples at a distance of 50 mm from the belt edge and one from the center of the belt. The final result was provided in the form of the mean value obtained from the three measurements for each cover.

![Figure 1. The test of rig](image)

3.2 Measurement uncertainty
Due to measurement uncertainty, the results of even the most scrupulous tests do not provide unequivocal information on the measured value and therefore the results were provided together with uncertainty range. Information on the uncertainty of test results is important for the testing laboratory, as well as for its clients and all institutions which later use the results for comparison purposes.

Measurement uncertainty was determined in accordance with EA-04/16 [11]. The main function of the document is to standardize the method of determining uncertainty ranges for test results. The document defines measurement uncertainty as a parameter related to the measurement result, characterizing the dispersion of values which may be attributed to the measured quantity. Measurement uncertainty may be calculated with the use of either Type a or Type B evaluation [12]. Type an evaluation is used when many independent measurements of one input value may be performed in identical conditions, and the adequate number of the degrees of freedom exceeds 30 [13].

Type B evaluation is used, when statistical analysis of a measurement series cannot be performed. Such situation occurs when conveyor belts are tested with the use of standardized methods which allow for a limited number of samples. In Type B evaluation, standard uncertainty is calculated on the basis of information on the possible variability range of this value, with consideration inter alia to:

- data obtained from calibration certificates;
- data obtained from previous tests;
- technical specification from the manufacturer;
• uncertainties related to reference values;
• own experience.

Standard combined uncertainty $u(Y)$ is calculated from relationship (1):

$$u(Y) = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2(x_i)}$$  \hspace{1cm} (1)

where
- $c_i = \frac{\partial f}{\partial x_i}$ – coefficients of sensitivity equal to the values of partial derivatives calculated for mean input values,
- $u_i(x_i)$ – standard partial uncertainties for input values,
- $m$ – number of input values.

4. Results and analysis

Table 3 contains the results of laboratory tests on the adhesion strengths of belts manufactured in 1987, 1998, 2007 and 2016. The standardized minimum belt adhesion strength which ensures safe operation of belts of this type should be 12 N/mm. The analysis of the data from Table 3 suggests that the belts manufactured in 1987 and 1998 do not meet this criterion.

| Year of production | Sample no. | Adhesion strength, \(N/mm\) |
|--------------------|------------|-----------------------------|
|                    |            | carrying pulley              |
| 2016               | 1          | 32.8                         |
|                    | 2          | 34.9                         |
|                    | 3          | 30.6                         |
|                    | 1          | 12.0                         |
| 2007               | 2          | 13.2                         |
|                    | 3          | 11.7                         |
|                    | 1          | 7.7                          |
| 1998               | 2          | 8.0                          |
|                    | 3          | 9.1                          |
|                    | 1          | 7.0                          |
| 1987               | 2          | 6.7                          |
|                    | 3          | 9.0                          |

Table 4 contains mean adhesion values of the covers to the belt core with expanded uncertainty ranges. The expanded uncertainty provided in the table results from standard uncertainty multiplied by extension coefficient $k = 2$, which offers a confidence level of approximately 95% in normal distribution [12, 13]. The results indicate that expanded uncertainty range at the 95% confidence level does not exceed 10% of belt adhesion strength. The only exception is observed in the case of the twice higher results for the adhesion of the carrying cover to the core in belts manufactured in 1987 and 1998.
Table 4. Adhesion strength of the covers to the belt core with uncertainty ranges

| Year of production | Belt age*<sup>,</sup> years | Adhesion strength, N/mm | Measurement uncertainty, % |
|-------------------|---------------------------|--------------------------|-----------------------------|
| 2016              | 1                         | 32.8; 3.3                | 25.7; 2.6                   |
| 2007              | 10                        | 12.3; 1.2                | 14.4; 1.0                   |
| 1998              | 19                        | 8.3; 1.6                 | 7.2; 0.4                    |
| 1987              | 30                        | 7.6; 1.5                 | 7.8; 0.8                    |

*belt age is understood as the period between the year of belt production and the year of post-aging tests, i.e. 2017

Tests of belt adhesion strength and of other belt parameters are frequently preceded by thermal belt aging. Thermal aging is performed in order to estimate how the parameters of the belt are affected by the flow of time. Thermal aging is an accelerated simulation of natural aging. The test consists in a controlled exposure of test samples to deteriorating conditions, i.e. to the influence of air at atmospheric pressure but increased temperature. Thermal aging is performed at defined time intervals and temperature. The goal of this procedure is to deteriorate the physical properties of test samples. This method, however, does not fully reflect all changes which accompany natural aging processes. In order to define the deterioration degree, belt samples should be examined after the aging process and the results obtained should be compared with the results of pre-aging examinations. This is the only method which allows the determination of how aging affects belt strength properties. Therefore, Table 5 includes the adhesion values of the rubber covers to the core as specified for new belts. The values presented in Table 5 are averaged for the carrying cover and the pulley cover. The mine did not provide either source data on the adhesion tests or the calibration certificates of the testing machines and therefore the values in the table are provided without measurement uncertainties. The data from Table 4 and Table 5 were also used to provide mean adhesion values after natural aging, expressed as the percentage of the original value of the new belt.

Table 5. Adhesion test results of the covers to the core for new belts

| Year of production | Belt age, years | New belt, * N/mm | After aging, ** N/mm | Decrease in adhesion value, % |
|-------------------|----------------|-----------------|---------------------|-------------------------------|
| 2016              | 1              | 29.2            | 29.2                | 0.0                           |
| 2007              | 10             | 26.6            | 13.3                | 50.0                          |
| 1998              | 19             | 23.0            | 7.7                 | 66.5                          |
| 1987              | 30             | 22.9            | 7.7                 | 66.4                          |

*no measurement uncertainty was provided due to insufficient source data from the mine. Mean values were provided for both covers; **tests performed in 2017

Figure 2 shows the relationship between relative values of adhesion between the covers and the belt core, depending on belt age. The most significant adhesion decreases – at the level of 66% – was observed for belts manufactured in 1987 and 1998 (belt age 30 and 19 years, respectively). The most intensive decrease of relative adhesion values, on the other hand, was observed within the first ten years from the belt production year. Relative adhesion values decreased by up to 50% in comparison to the original values. During subsequent 9 years of natural belt aging, the adhesion values were
lowered by further 16%. After this period, relative adhesion values stabilized and did not further decrease for the belt manufactured in 1987.

As the conveyor is operated, numerous defects of belts occur frequently, which are related to the transportation of the mined material. The defective belt segment is typically replaced with a new belt section of identical core structure and tensile strength. Various belt segments are typically stored in mines. These belt segments have been removed from conveyors, e.g. when a conveyor was shortened, and can be still used to replace the defective segments. The age of some of these segments is above 30 years. Therefore, the key question is whether such sections can be still used. In order to answer this question, one must investigate how the time and the process of natural aging, covering the annual range of air temperatures, as well as precipitation and weather conditions, influence the strength parameters of conveyor belts.

**Figure 2.** Relative decrease in adhesion value of the covers to the steel-cord belt core with reference to the original value and belt age.

**Figure 3.** Influence of belt age on the adhesive strength of the covers to the belt core
Figure 3 represents adhesion strength changes plotted for the period of up to 30 years of their natural aging. The dashed line denotes the minimum adhesion value which must be preserved in order for the belt to be accepted for further use on a conveyor in a mine. The belt is installed on the conveyor by assembling a splice (joint). If the adhesion parameters of the connected belts do not meet the limit values, i.e. remain below 12 N/mm, as indicated by the dashed line, then the strength of such joint will be lower than expected. The analysis of the curve in Figure 3 suggests that the tested belts reach the limit adhesion value after a period of almost 12 years from their production year (12 years of natural belt aging).

5. Conclusions

The tested belts were dedicated for operation in open-cast mines, where they were subjected to varying atmospheric conditions: temperatures both above and below zero degrees Celsius, sun, rain and snow, as well as wind and other weather conditions typically found in open-cast mines. Being operated in actual mining conditions, they provide valuable information on how adhesion strength of the covers to the belt core changes in time. The analysis of the test results demonstrated what follows:

- the natural aging time (belt age) has a negative impact on the adhesion strength of the covers to the core of steel-cord belt type ST 3150 by lowering its value;
- the greatest influence of natural belt aging on the decrease of adhesion strength is observed over the first 10 years of the aging process (in the analyzed case, relative adhesion value was reduced by 50% in comparison to the original value);
- further decrease in the adhesion value between the 10th and 19th year of belt aging was almost threefold smaller and reached approximately 16%;
- in the subsequent 10 years, no further adhesion decrease was observed and it may be therefore assumed that the adhesion value in a 20-year old, naturally aged belt becomes stable, albeit below the limit value required in the mine;
- the adhesion strength of the covers to the belt core disqualifies the belts manufactured in 1987 and 1998 from being reused in the form of e.g. insets in place of damaged belt fragments, but does not disqualify them from further operation, if they are already installed on the conveyor – the condition of such belts should be monitored, however, in order to prevent their unexpected breaks.

The above conclusions have been based on the test results of four conveyor belts aged in actual mining conditions. In order to provide further details, future tests should cover other types of belts from various manufacturers and having various strengths.

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