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defects of joints of conveyor belts; simulation of failures;
lifetime prediction

Adil TEMERZHANOV, Ivan STOLPOVSKIKH
Kazakh National Technical University named after K.I. Satpayev
Satpaev st. 22, 050013 Almaty, Kazakhstan
Aleksander SŁADKOWSKI
Silesian University of Technology, Faculty of Transport
Krasiński st. 8, 40-019 Katowice, Poland
**Corresponding author*. E-mail: temerchanov@mail.ru

ANALYSIS OF RELIABILITY PARAMETERS OF CONVEYOR BELT JOINTS

Summary. In the article was found the causes defects vulcanized joints based on analysis of operating of conveyor belts, given the physical and mathematical model of failure joints. Measures have been developed to improve the reliability of the joints of conveyor belts.

АНАЛИЗ ПОКАЗАТЕЛЕЙ НАДЕЖНОСТИ СТЫКОВЫХ СОЕДИНЕНИЙ КОНВЕЙЕРНЫХ ЛЕНТ

Аннотация. В статье на основе анализа эксплуатации конвейерных лент установлены причины возникновения дефектов вулканизации стыков, дана физико-математическая модель формирования отказа стыкового соединения. Разработаны мероприятия по повышению надежности эксплуатации стыков конвейерных лент.

1. DETECTION OF DEFECTS IN JOINTS OF CONVEYOR BELTS

Reliability and efficiency of mining conveyors depends to a great degree on vulcanization defects of the conveyor belt joints [1]. It was proven by Veksler G.Z. in his work that joints are the weakest component of the conveyor belts [2]. Consequently it is critical technological and scientific challenge to increase reliability and durability of the mining conveyor belt joints. Defects and failures of the joints tend to hamper normal operations and efficiency of manufacturing process, increase consumption of conveyor belts, operational complexity, and cost of transportation. The open-pit mining downtime caused by damaged and broken belt joints is around 21-22%. Joint violations cause about 30% of wear in the conveyors transporting lumps. Operability of vulcanized joints varies very widely in the same operating conditions: in some cases it is close to the main belt operability, in others violations occurs after several weeks and sometimes even days of work (fig. 1, 2).

According to numerous studies [1-3] the reduction in strength, durability and operability of the joints is due to following vulcanization defects: a) changes in the thickness of the rubber layer (0.1 ... 4 mm); b) the difference in the quality of rubber middle layer and durability of joint between this layer and covers in the joint areas (in some places rubber is monolithic and the strength of its connection with the covers is above average, while in others, often on large areas, joint consists of a porous or sponge rubber with low physical and mechanical properties and has little connection with the covers);

c) poor quality of vulcanization and burnout of discrete sections of the rubber layer of joints. These defects typically appear in the rubber with the ages of the joints.

Fig. 1. General view of conveyer belt failure on Joint-Stock Company "Altyntau Kokshetau": 1 - conveyer belt; 2 – rope

Рис. 1. Общий вид выхода из строя конвейерной ленты на АО «Алтынтау Кокшетау»: 1 – конвейерная лента; 2 - трос

The conveyor belt joints vulcanization defects are primarily caused by presses with rigid plates, heating elements of concentrated heated wire, and bars with tie bolts which don't provide necessary stability of the temperature and pressure distribution over the entire area of vulcanization. Due to differences in thickness of the joints, reaching 4.2 to 5.25 mm, the differences in thickness of individual plates, and deflection of structural elements of vulcanization presses the heated layer of rubber moves from the areas with excess pressure to the adjacent areas with lower pressure.

During belt joints vulcanization the temperature of the heated plates in the press can deviate from optimal temperature in range -10 and +50˚C while only allowed ±2˚C. Duration of vulcanization in overheated areas is twice the calculated temperature compared with optimal temperature. These overheated joint areas are the source of joint destruction which reduces operability and reliability of conveyor belts.

Significant metal consumption and large mass of individual components of vulcanization presses, the complexity and duration of assembly and disassembly of the presses are other significant drawback of currently used conveyor belt joints vulcanization technology.

In the Institute of Geotechnical Mechanics (IGTM) of the National Academy of Science of Ukraine, based on the performance of complex scientific - experimental studies were sought and developed a fundamentally new and promising designs of vulcanized presses to ensure sufficient

stability of the basic technological parameters of the vulcanization process, i.e. the specific pressure and temperature of heating the entire area of the joint. Resulting in increased strength, durability and reliability in the joints of the compounds, increasing the service life of belts and conveyor transport efficiency as a whole.

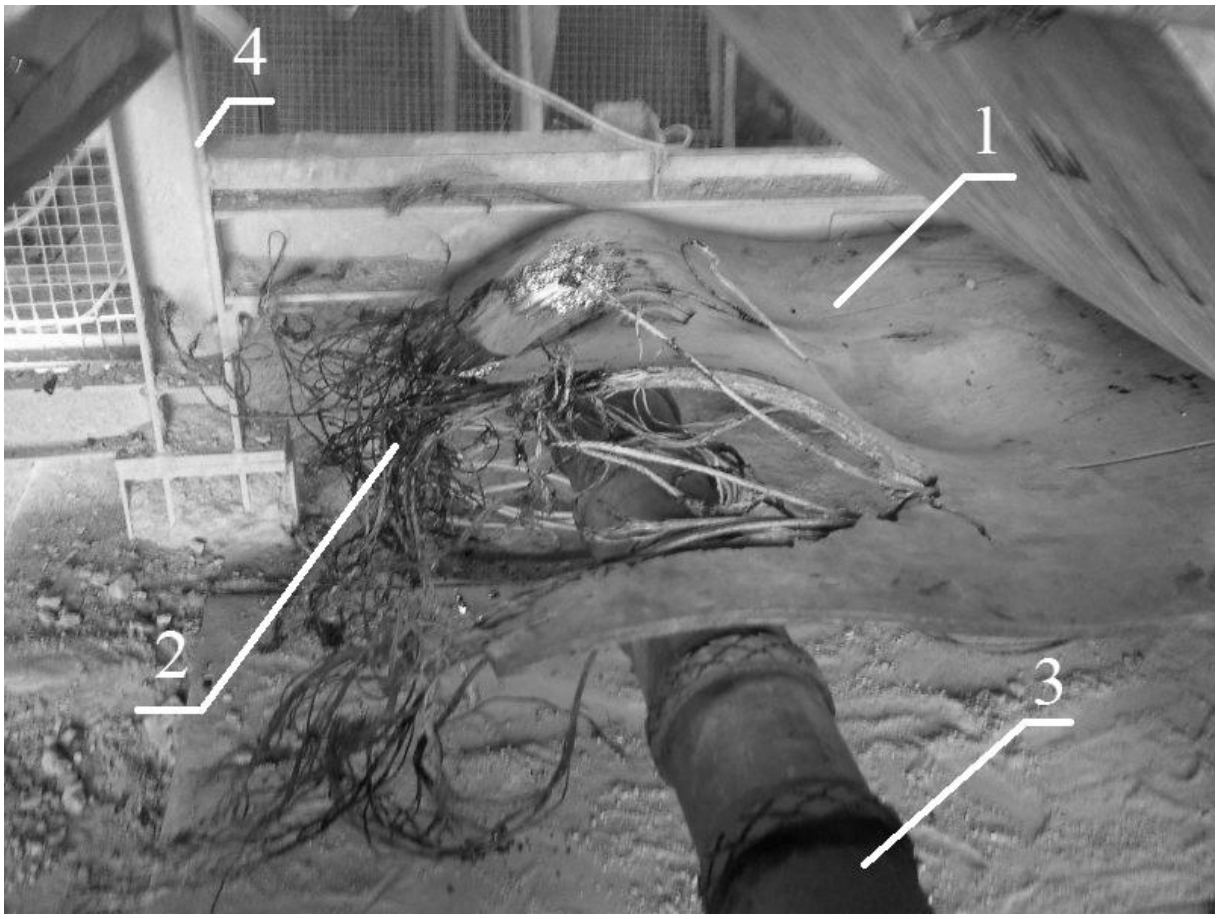

Fig 2. Fragment of break of connection of conveyer belt with steel rope cords: 1 – conveyer belt; 2 – broken connection; 3 – roller bearing; 4 – pillar of enclosure

Рис. 2. Фрагмент разрыва соединения резинотроссовой конвейерной ленты: 1 – конвейерная лента; 2 – место разрыва соединения; 3 – роликоопора; 4 – стойка ограждения

In the prospective design of Sciences of Ukraine press IGTM applied flexible heating plates and flexible camera at the node pressure to ensure uniform distribution of pressure over the area of vulcanizing site, regardless of changes in its thickness and the presence of depressions or protrusions in certain places.

Physical and mathematical model of conveyor belt joints failures is a continuous Markov chain. The selected parameter, in this case is the wear of a rubber layer of the joint. Parameter value changes over time are used to quantify reliability and durability. In order for the conveyor belt joints to be in workable state its technical parameters have to be in the tolerance zone. One of the key parameters of conveyor belt joints is distributed pressure over vulcanization area. The rate of deterioration of key technical characteristics of the joints depends on several factors including physical and mechanical properties of transported mining material, technical parameters of the conveyor and conveyor belts, drop height, belt speed, frequency of dynamic system of the conveyor, environmental characteristics and humidity. Operability of conveyor belt joints is determent by its wear limits. The first approximation accepts linear wear model of the cover and rubber layer of conveyor belt. The initial value of the corresponding parameter is random because of differences in manufacturing technology

and assembly. The rate of wear of the cover and belt joints under defined conditions remains constant on average for the entire period of operation. These studies continue works described in the paper [4].

2. SIMULATION OF FAILURES

In the calculation below P_c is the probability of no-failure functioning of the cover, P_{rl} is the probability of no-failure functioning of the rubber layer and n is the number of covers in the belt joint, then probability of the belt joint working without failures with independent probability of failures of individual covers and joint rubber layer is determined by the following equation.

$$P = P_c \cdot P_{rl}^{2(n+1)} \left[1 - \prod_{i=1}^{n} (1 - P_c) \right] \tag{1}$$

Wear of the joints due to normal operations leads to gradual reduction of quantitative indicators of reliability, which are distributed by normal law.

Applying the normalized Laplace function, the probability of the joint rubber cover not failing as it reaches the wear limit is determined by the following expression:

$$P_{rl} = 0,5 + \Phi\left[\left(x_{\max} - x_{iw} - wt \right) \Big/ \left(\sqrt{\sigma_1^2 + \sigma_2^2 + (\sigma_3 \cdot t)^2} \right) \right] \tag{2}$$

where – $x_{\max}$ and x_{iw} is the allowed and initial wear; w is the wear rate; t is operating time; σ_1 , σ_2 , σ_3 is respectively standard deviations of the permissible and initial wear, and the wear rate.

Ordinary Least Squares method is used to determine equation of the wear of the conveyor belts joints:

$$x = x_{iw} + 12,84 \cdot T^a \cdot b \cdot z^c, \tag{3}$$

Where x is current wear in micrometer; T is actual working hours; z is air pollution of work area; and a, b, and c are the empirical coefficients, equal to 2.86; 5.32; and 1.117 correspondingly.

It is necessary to consider the discrete nature of shock pulses at certain pay load for the joints, occurring during loading and when conveyor belt loaded with heavy rocks runs over the rollers during which the probability of deviation from the normal static pay load should be not more than 0,001 [8] for specified duration.

At the end of the belt warranty period the accumulated fatigue damages and wear leads to a breakage of conveyor belt joints. Additional experiments have to be conducted to quantify reliability trends of the conveyor belt joints, distribution characteristics, and parameters of no-failure operations.

Based on the physical nature of conveyor belt joints failures due to abrasive and fatigue wear, and analysis of the results of numerous experiments, the distribution of uptime is subject to two-parameter Weibull law with probability density [1-3]

$$f(t) = \alpha \cdot \nu (t - t_0)^{\alpha - 1} \exp\left[- \nu (t - t_0)^{\alpha} \right] \tag{4}$$

where ν and α are calculated parameters and t_0 is the minimum operation time to first failure or a threshold operation time level with the failure probability of zero.

The number of joints under observation N is defined at a given relative accuracy of ε=0,1; confidence probability of λ=0.95, and coefficient of variation K_{var}=0.58...0.68 using following formula [2]

$$(\varepsilon+1)^{\alpha} = 2N / x^2_{1-\lambda,2N} \quad , \tag{5}$$

where x^2 is the quantile of Pearson's distribution.

Number of belt joints to be tested for durability should be in the range of 85÷105 although observation can be conducted with much greater number of joints which leads to the greater accuracy of results.

3. LIFETIME PREDICTION OF CONVEYER BELT JOINTS

Adequacy of the law of the empirical distribution to the hypothesis should be estimated using the criterion of Pearson.

If no single failure occurs during observed period which exceeds guaranteed operation time of the joint then the upper confidence limit of the probability of failure is defined as follows:

$$P_{pf} = 1 - \sqrt{1-\lambda} \tag{6}$$

The number of required tests of the belt joints at the confidence level of 0.96-0.99 is determined from the following equation:

$$N = \frac{\lg(1-\lambda)}{\lg(1-P_{pf})} \approx 105...158 \tag{7}$$

The parameters of the Weibull low ν and λ are determined graphically according to the system of equations:

$$\begin{gathered} \nu = B \Big/ \left[\sum_{i=1}^{B} t_i^{\alpha} + (N-B) \cdot T^{\alpha} \right] \\ \left(\frac{B}{\alpha} + \sum_{i=1}^{B} \ln t_i \right) \cdot \left[\sum_{i=1}^{B} t_i^{\alpha} + (N-B) T^{\alpha} \right] - B \left[\sum_{i=1}^{B} t_i^{\alpha} \cdot \ln t_i + (N-B) T^{\alpha} \ln T \right] = 0 \end{gathered} \tag{8}$$

where B is the number of failed joints; t_i is the operation time between failures.

Parameter α fluctuates in the range of 1.4-1.6 and confidence interval for parameter ν is determined with probability of λ=94.5%.

The lifetime of conveyer belt joints (coefficient gamma [8]) can be calculated using following equation after determining the point estimates of the parameters of reliability:

$$T_{p\alpha} = \left[\frac{1}{\nu} \left(-ln \frac{\alpha}{100} \right) \right]^{1/\alpha} + t_0 \quad . \tag{9}$$

Its value is set to be $\alpha = 84\%$ in order for the conveyor belts to be suitable for mass production so that belt failures do not lead to the failures and breakage of the mining equipment and maintenance cost is kept low.

4. CONCLUSION

Analysis of the conveyor belt operations has revealed that decrease in strength, durability and reliability in conveyor belts is due to vulcanization defects and failures of conveyor belt joints. Physical and mathematical model of conveyor belt failures yielded analytical results of probability of no-failure operations of the joints, probability of no-failure operations of the joint rubber covers, and equation of the wear of the conveyor belts joints.

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