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PREDICTING THE WORKING TIME OF MULTI-PLY CONVEYOR BELT SPLICES IN UNDERGROUND MINES

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Abstract: Knowledge about the service life of the splices before they are made is extremely valuable information for the users of belt conveyors because having additional technical data about the conveyor and the place of its installation makes it possible to forecast the working time of the joint. The results of calculations of the service life of joints of multiply textile conveyor belts are presented. The calculations were made using a computer program specially created for this purpose, which predicts the service life of the joints before they are made. The program was created due to the implementation of research grant No. PBS3/A2/17/2015 financed by the National Center for Research and Development (NCBiR). The simulation results were compared with the data showing the working time of the joint in actual conditions of its operation in an underground mine. Comparing the simulation results of failure-free operation of joints with accurate data on the operation time of joints in the analyzed mines, it was noticed that the joints could work longer. Depending on the mine, it was from 3 to 8 months. The simulation did not consider sudden phenomena that could occur during the belt and joint operation. It was assumed that the belt operated smoothly, did not run off the conveyor, did not rub against the conveyor structure, etc. Each such phenomenon shortens its working time. The simulation results also showed that the joint made by hot vulcanization is characterized by a longer working time than the one made by cold gluing.

Keywords**:** *multi-ply textile conveyor belt, conveyor belt splice, splice service life, splice durability*

1. INTRODUCTION

During the installation of a new belt and the replacement of individual sections of the belt loop, conveyor belt splices are made. The appropriate type of splice depends on

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whether it is a belt with a textile core or steel cords (Kirenli and Demirsöz 2022; Long et al. 2018; Chuen-Shii et al. 2013). Mechanical, cold-glued, and hot vulcanized splices are used in belts with a textile core. On the other hand, belts with a steel cord core are connected only by the hot vulcanization method. Mechanical splices use the cohesion of the belt core, through which the elements fastening the two ends of the belt pass. There are two types of mechanical splices – detachable and non-detachable. The advantages of this type of connection are that they are easy to make, quick, and cost low. The disadvantage of this type of connection is the much lower strength of the splice than the belt's strength. This type of splice is mainly used in emergencies (Hardygóra and Żur 1996).

Splices made by gluing can be used for all types of textile belts. They are characterized by much greater strength than mechanical splices. The advantage of this connection is its ease of execution. Connecting a conveyor belt using cold gluing is possible thanks to special cold-curing adhesives. This method does not require elevated temperatures, but the connecting substances must be applied precisely and have the appropriate thickness. Before the belt is intended for reuse, the splice must wait until it reaches full strength. In underground mines, where humidity is high, the seasoning time will be longer than in conditions that occur on the surface. The time to make such a splice is estimated at 4 to 8 hours (Hardygóra et al. 1999)

Hot vulcanization splices can be used for all types and kinds of belts. Splices made using this method are characterized by the highest strengths of 60÷100% compared to the strength of the belt. The disadvantage of the splice is its laboriousness. To make the splice, it is necessary to use cumbersome equipment – a vulcanization press. They provide the required pressure and vulcanization temperature. If the vulcanized splice is to be made in conditions of coal dust or methane explosion hazard, the press must have an appropriate safety certificate. This is associated with the high costs of such equipment therefore the vulcanized splice is more expensive than the cold-glued one (Bajda et al. 2016).

Splicing multi-ply belts using cold gluing is cheaper than hot vulcanizing. However, the strength of a cold-glued splice is about 60% of the strength of the belt. The splice may be characterized by additional lower strength when it is made poorly or when low-quality materials are used (Kozłowski et al. 2020; Kirjanów 2015). Even if you connect high-quality and durable belts, the materials used for splicing do not match the belt; such a splice will not achieve the required strength and will deteriorate faster. This means the splice will have to be replaced and repaired more often, associated with additional costs. Before a new splice is put into operation, it must be seasoned for an appropriate time. The unplanned downtimes on strategic conveyor belts can cause severe losses for the mine. The lower price of glued splices does not compensate for their much lower durability. The assumed relative difference in the cost of a glued splice is about 36%, while the assumed relative decrease in durability was 66.7% (Błażej et al. 2022; Jurdziak 2000). Mines wanting to save money use cheaper splices, which can contribute to higher costs associated with repairs and unplanned downtime of conveyors.

However, knowing the exact parameters of the conveyor belts, the materials to be used for the splice, and the conveyor on which the belt will operate, it is possible to calculate the expected working time of the splice before it is made (Hardygóra et al. 2012; Bajda et al. 2018). Thanks to these predictions, it is possible to determine what strength parameters the belt and its splice should have so that the belt conveyor can operate for as long as possible without the need to repair the splice. Cold glued splices' low durability affects the belt loop's low reliability and entails high costs of emergency stops and production losses caused by this stop (Bajda et al. 2017). It should be remembered that the splice is the weakest link in a closed belt loop on the conveyor and determines the reliability of this means of transport (Komander et al. 2011). Therefore, it is necessary to predict the durability of the splice before it is made.

Another aspect in favor of predicting the durability of the splice is the possibility of transporting the crew using belt conveyors. The conveyor can transport employees if the strength of the splice is not less than 60% of the strength of the belt operating on the conveyor. As a result, splices with the highest possible strength should be used for transporting crew in mines. The crew is transported faster and arrives at the workplace earlier. Moreover, accidents involving people walking on the mine's sidewalks will decrease (Tokarczyk et al. 2019; Kamiński 2021).

The decision made by the mine regarding the use of the appropriate method of splicing the conveyor belt is an important issue related to the efficiency of the mine's work. It is influenced by many factors related to the parameters of the working conveyor and belt, as well as economic factors. Knowledge of the service life of the splice before it is made is extremely valuable because it allows one to know the working time of the splice and also supports the organization of work in the mine. For this purpose, a unique computer program was developed that allows for the prediction of the durability of a splice before it is made (Project NCBiR 2018).

The article presents calculations of the predicted working time of splices on selected belt conveyors operating in four underground mines. The conveyors transport hard coal, and one of them is additionally used to transport the crew. Simulation calculations were carried out to predict the working time of the splice in the mines for two variants of the splice: cold glued and hot vulcanized. The simulation results were compared with the actual working time of splices operating on the analyzed conveyors in mine conditions. The splices in all mines were made by the same company, which, when winning the tenders for making the splices, had information about the dates of their replacement and, thus, their actual working time on the conveyors.

2. RESEARCH METHODOLOGY

Belt conveyors transporting coal in three hard coal mines were selected. They were marked with the symbols: mine “I”, mine “II”, and mine “III”. These mines were chosen because they had the appropriate data on the belt conveyors selected for simulation calculations. A fourth mine, marked with the symbol “IV”, was also selected, where conveyors are also used to transport crew.

In the mine “I” located in Upper Silesia, there is a conveyor on which the operating time of the connection will be predicted. The mine is considered one of Poland’s most modern and extensive (Antoniak 2007). It mines non-methane deposits. The mine uses conveyor belts with a width of 1200 to 1600 mm. The simulation will use a connection located on the conveyor on which a belt with a width of 1200 mm and a nominal strength of 1600 kN/m has been installed. This is a multi-ply belt with four fabric plies. The belt is of the GTP type, meaning it is a flame-retardant mining belt. The conveyor worked 20 hours a day. The belt speed is 3.15 m/s, transporting an average of 18 000 tons of coal daily. A two-drum drive system is installed on the conveyor, which, together with the return and tensioning drums, creates a system with seven drums on which the belt is bent. The length of this conveyor is 400 m.

Another conveyor belt splice analyzed is located on the conveyor in mine “II”. The mine has coal deposits classified as category III methane hazard. The conveyor system uses 1400 mm wide belts. The simulation calculations will use the splice on the conveyor, on which the 1400 mm wide belt with a nominal strength of 1600 kN/m operates. This is the same type of belt as in mine “I”. The conveyor also operates 20 hours a day. On average, it transports about 22000 tons of coal per day. The belt speed is 3 m/s. Like mine “I” has a two-drum drive system; the total number of drums in contact with the belt and bending that occurs on them is 7. The length of the conveyor, on which the splice subject to analysis is located, is 624 m.

The next analyzed splice is located on the mine “III” conveyor. The mine uses conveyors on which 1200 mm wide belts operate. The analyzed splice is situated on the conveyor on which the same belt type operates as in the other mines. The conveyor also worked 20 hours daily and transported 12 000 tons of coal daily. The belt speed is 3.15 m/s. However, this is a much longer conveyor than the previous ones; its length is 1410 m. Asa result, a more extensive belt tensioning system and a three-drum conveyor drive system are used. The number of drums in contact with the belt on which it bends is 9.

The next analyzed splice is located on the mine “IV” conveyor. The conveyor is used to transport coal and the crew. Transporting the crew by belt conveyors, as the mine’s experience shows, is the most advantageous way of moving the crew in the workings, both for safety reasons, economic effect, costs incurred for its construction, and simplicity of the applied technical solutions. According to data from the mine, introducing this type of transport contributed significantly to increasing its profit because the crew is at the workplace faster, which means that the exploitation process lasts longer, affecting the financial profit (Kamiński and Orzeł 2014; Bogacz et al. 2022). In the area of the section where the crew is transported, there is a 1005-meter-long conveyor on which the joint selected for analysis is located.

It is essential for the mine that the splice on the conveyors transporting coal and miners is reliable and safe. Therefore, it is necessary that before the splice is made, the mine can predict how the choice of the splice, whether cold glued or hot vulcanized, will affect the safe travel of people and the transport of ore. This can be predicted by performing simulation calculations in a dedicated computer program. The Wrocław University of Science and Technology, specifically the Belt Transport Laboratory (LTT), has such software. It was created as a result of numerous research grants implemented in LTT. Knowing the values of the belts' strength parameters, the materials used to connect them, as well as the operating conditions of the conveyor and its selected parameters, it is possible to predict the time of failure-free and safe operation of the belt loop on the conveyor.

All the analyzed conveyors use a belt with the symbol GTP EP 1600/4 from the same manufacturer. The belt in question has four plies and a nominal strength of 1600 kN/m. According to the manufacturer's data, the ply strength of this type of belt is from 350 to 500 kN/m. GTP belts are flame-retardant belts. They are mainly used in underground hard coal mines at risk of methane and coal dust explosions. The splices operating in the four mines, with which the results of simulation calculations were compared, were made using the hot vulcanization method. The splices were made as three stages with the same step length of 400 mm (Bajda et al. 2018).

2.1. COMPUTER PROGRAM FOR CALCULATING THE DURABILITY OF SPLICES

A computer program was used to calculate the fatigue life of splices, and calculations can be made for both glued and vulcanized splices. The calculations are based on information from the mines on the specific conveyors, conveyor belts, and materials used to make the splices. Thanks to this data, the program calculates the fatigue life of the splice, which allows for estimating the expected time of its failure-free operation. The program is in Polish but can be adapted to other languages. The program was developed in the Belt Transport Laboratory of the Wrocław University of Science and Technology as part of the research project PBS3/A2/17/2015 (Project NCBiR 2018).

Figure 1 shows the program window with a visible place for entering data. After entering the parameters of the belts and materials used to make the splice, the program calculates the number of fatigue cycles the connection can perform before damage.

In the "Taśma" column, enter the following conveyor belt parameters:

- tensile strength, R_t, kN/m,
- modulus of elasticity of the belt, M_t, kN/m,
- shear strength, t_p, kN/m^2.

In the "Spoina Klejowa" column, enter the parameters taken into account when calculating the fatigue strength of the vulcanized splice. These are:

- rubber modulus, Mg, MPa,
- adhesive strength of the adhesive bond, T, N/mm,
- rubber tensile strength, Ts, kN/m^2.

In the last column, "Złącze", enter the parameters that apply to the cold glued splice. These are:

- delamination strength of the joint, R_r, kN/m,
- modulus of elasticity of the splice, M_z, kN/m,
- relative elongation of the adhesive joint, ε_z, mm/mm.

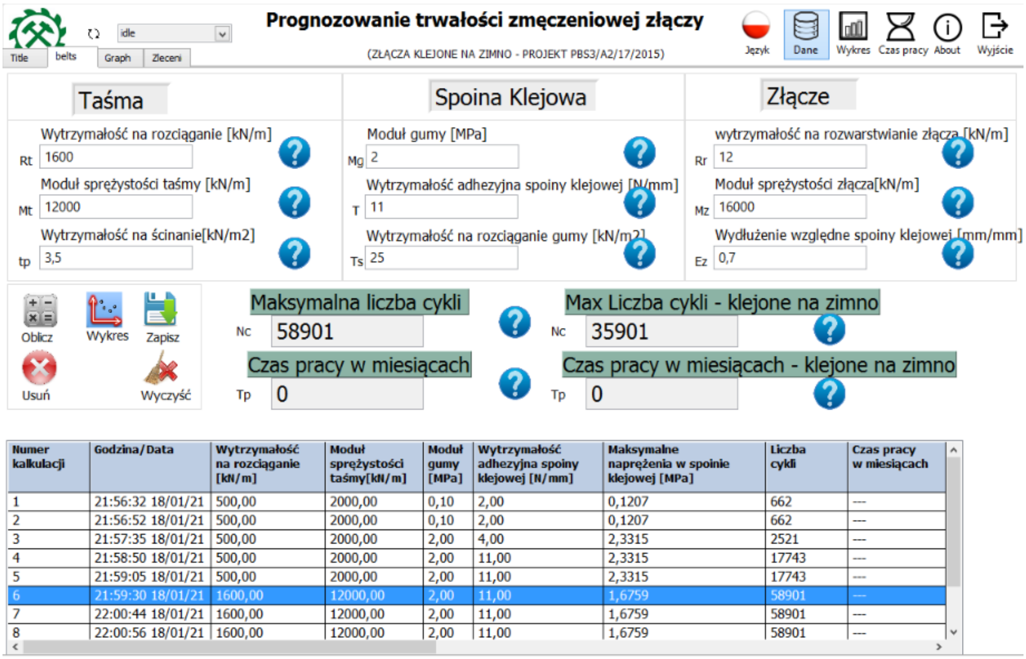

Fig. 1. Entering data into the program

At the bottom of the program window, you can see a table where information about the calculations is saved, including the calculation number, the time of its execution, the entered parameter values, and the obtained results. This information can be automatically saved and archived in an Excel spreadsheet. To read the research method used to determine the required parameter, click the "?" button. The values of most of the parameters needed for the program are determined according to current international ISO standards. In the case of determining the value of the relative elongation of the adhesive bond, tests should be carried out based on the research method developed by the LTT (Bajda and Hardygóra 2021).

Based on the parameters entered for the belt and the vulcanized splice, the program calculates the maximum number of fatigue cycles (NC), after which its destruction will occur. They are calculated using the formula (1)

$$NC = 12.3 \cdot (M_t / R_t)^{1.91} \cdot R_r^{1.93} \tag{1}$$

where:

M_t – modulus of elasticity of the belt, kN/m,
R_t – tensile strength of the belt, kN/m,
R_r – delamination strength of the splice, kN/m.

This relationship results from laboratory tests of the fatigue life of vulcanized splices, which LTT performed as part of the research project (Project NCBiR 2018). This study showed how the stresses in the adhesive joint develop along the length of individual splices of multi-ply conveyor belts. The studies also showed that the modulus of elasticity of the connecting belts and the adhesive strength of the inter-ply rubber to the connected plies fundamentally influence the durability of the splice. As a result of the analysis, it was possible to calculate the maximum number of fatigue cycles that a specific vulcanized joint can perform before it is damaged.

The relationship enabling the calculation of the number of fatigue cycles (LC) that a cold glued splice can perform is described by the formula (2)

$$LC = 0.002 \cdot R_r^{1.90} \cdot M_t^{0.27} \cdot Ts^{2.59} \cdot \varepsilon_z^{-3.90} \tag{2}$$

where:

M_t – modulus of elasticity of the belt, kN/m,
R_r – splice delamination strength, kN/m,
Ts – tensile strength of the inter-ply rubber, kN/m^2,
ε_z – relative elongation of the adhesive splice of the friction rubber at external splices, mm/mm.

The above relationship was developed based on numerous studies of cold-glued splices, as well as a result of the implementation of research project no. PBS3/A2/17/2015 in LTT. This relationship differs from formula (1) because, in cold-glued splices, stresses and deformations at the splices of external steps are several times greater. These differences result from the fact that the chemically cured glue does not behave like rubber. Therefore, the splice at the splices of steps is subject to very high stresses, several times more significant than the splice made by the hot vulcanization method.

By entering data on the length of the conveyor, the number of drums in contact with the belt, the belt speed, and the number of working hours per day and days in a month, the program predicts the working time of the splice (*Tp*) in months. The durability of the splice, in other words, the time of its failure-free operation, was calculated based on the formula (3)

$$Tp = \frac{2 \cdot NC \cdot L_p}{l_b \cdot v \cdot l_d \cdot (3600 \cdot l_g)}, \tag{3}$$

where:

NC – number of fatigue cycles,
L_p – the length of the conveyor, m,
l_b – number of drums,
v – conveyor speed, m/s,
l_d – number of working days per month,
l_g – number of working hours per day.

Calculations allow for comparing the predicted working time of a hot vulcanized and cold-glued splice. The same belt with the same parameters but different adhesive bond properties may work much shorter. It all comes down to costs. If the mine knows about the splice's working time, it may make a more expensive but durable splice that can work much longer in the same conditions.

3. TEST RESULTS AND DISCUSSION

Below are presented the results of simulation calculations, in which information on the forecasted service life of the splice expressed in months was obtained. Some parameters were changed in the calculations to emphasize their importance and impact on the service life of the entire belt loop (Jary 2021). Table 1 presents the effect of the elastic modulus of the belt and the elastic modulus of the splice on the service life of the vulcanized and cold-glued splice. The calculations were performed using the example of a conveyor operating in the "III" mine. The remaining parameters used in the calculations are constant and do not change: the tensile strength of the belt is 1600 kN/m, the shear strength is 3.5 kN/m^2 and the

Table 1. Summary of results for the "III" mine in the case of a variable modulus of elasticity of the belt

No.	Elastic modulus of the belt, M_t [kN/m]	No. of fatigue cycles performed by the splice [cycle]		Expected splice operating time T_p [months]	
		Cold-glued, L_c	Vulcanized, N_c	Cold-glued	Vulcanized
1	14 000	252 283	125 871	26	13
2	15 000	256 976	143 588	27	15
3	16 000	261 445	162 413	27	17
4	17 000	265 714	182 338	28	19
5	18 000	269 802	203 358	28	21
6	19 000	273 728	225 466	28	23
7	20 000	277 504	248 658	29	26
8	21 000	281 145	272 929	29	28
9	22 000	284 661	298 273	29	31
10	23 000	288 061	324 686	30	34
11	24 000	291 355	352 164	30	36

rubber modulus is 2 MPa. The delamination strength of the splice is 14 kN/m. For the cold--glued splice, the tensile strength of the inter-ply rubber was assumed to be 24 kN/m^2 and the relative elongation of the adhesive bond is 0.45 mm/mm.

As the modulus values increase, a tendency can be seen to increase the number of fatigue cycles. The results show that the modulus of elasticity is not a key parameter in a cold-glued splice. However, it is an essential factor influencing the number of cycles and the durability of a joint made by the vulcanization method. An increase in the modulus value from 14 000 kN/m to 24 000 kN/m causes an almost three-fold difference in the durability of the splice in the case of a vulcanized splice. In a cold-glued splice, an increase in the value of this parameter in the same range causes an increase in fatigue cycles by only about 15%. This relationship results from the M_t/R_t ratio: the higher it is, the more fatigue cycles the vulcanized splice will perform.

Table 2 shows the influence of the splice's delamination strength on its working time. The calculations were made using the "II" mine as an example. The remaining parameters were constant and amounted to the belt's tensile strength, 1600 kN/m, and the shear strength, 3.5 kN/m^2. The elasticity modulus of both the belt and the splice is 18 000 kN/m.

More than doubling the delamination strength from 6 to 14 N/mm^2 causes about a fivefold increase in the number of fatigue cycles performed by the splices, which extends their operation by about 10 months in the case of both splices. Therefore, one should strive to obtain the highest possible value of this parameter.

Table 2. The impact of splice delamination on its service life

No.	Resistance to splice delamination, R_r [kN/m]	No. of fatigue cycles performed by the splice [cycle]		Expected splice operating time, T_p [months]	
		Cold-glued, L_c	Vulcanized, N_c	Cold-glued	Vulcanized
1	6	35 825	39 675	2	3
2	7	48 004	53 412	3	3
3	8	61 854	69 102	4	4
4	9	77 353	86 727	5	6
5	10	94 480	106 270	6	7
6	11	113 218	127 717	7	8
7	12	133 553	151 055	9	10
8	13	155 469	176 272	10	11
9	14	178 954	203 358	11	13

Table 3 presents the results of calculations of the effect of relative elongations of the adhesive bond of a cold-glued splice on its predicted working time. The splice from the "IV" mine was selected for analysis, the only one of the analyzed slices operating on a conveyor used to transport people. What would happen if the splice in the "IV" mine was made using the cold-gluing method? How quickly does the working time of such a splice shorten due to increasing relative elongations of the adhesive bond?

Table 3. Summary of results for the mine "IV" for the variable value of relative elongation of the adhesive bond

No.	Relative elongation of the adhesive bond, ε_z [mm/mm]	No. of fatigue cycles performed by the splice, *Lc* [cycles]	Expected splice operating time, T_p [months]
1	0,32	101 8594	95
2	0,35	718 371	67
3	0,40	426 945	40
4	0,45	269 802	25
5	0,50	178 954	17
6	0,55	123 438	11
7	0,60	87 942	8
8	0,65	64 378	6
9	0,70	48 231	4
10	0,75	36 861	3
11	0,80	28 665	3
12	0,85	22 634	2
13	0,90	18 114	2
14	0,95	14 673	1
15	1,00	12 015	1

The calculations assumed an elongation value from 0.32 to 1.00 mm/mm. The remaining belt parameters are constant and are: belt strength 1600 kN/m, shear strength 3.5 kN/m^2, delamination strength 14 kN/m, and rubber tensile strength 24 kN/m^2. The splice elasticity modulus is 18000 kN/m. The results presented in Table 3 show that the

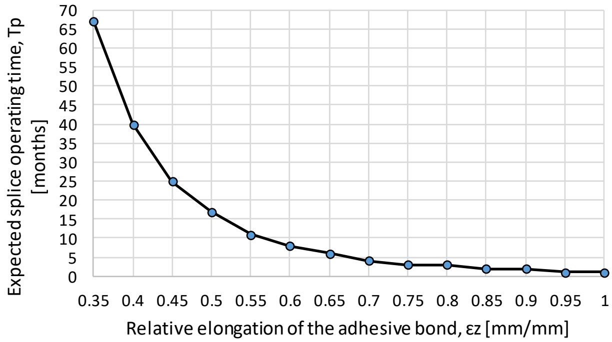

Fig. 2. Dependence of splice operating time on relative elongation of the adhesive bond (mine "IV")

relative elongation of the adhesive bond has a key impact on the maximum number of fatigue cycles the splice can perform. The splice can perform about a million cycles when this parameter has low values at 0.32 mm/mm. However, such a low value is practically unattainable for a cold-glued splice. Most often, the value of this parameter is over 0.4 mm/mm. The value of this parameter is influenced mainly by the materials used to make the splice, i.e., chemically cured adhesives. The graph presented in Fig. 2 shows that the operating time of the analyzed splice decreases exponentially with the increase of the ε_z parameter.

Table 4 presents calculations of the influence of the inter-ply rubber's tensile strength on the splice's predicted operating time.

Table 4. Summary of results for mine "I" for the variable tensile strength value of the inter-ply rubber

No.	Rubber tensile strength, Ts [kN/m^2]	Relative elongation of the adhesive splice of the friction rubber ε_z [mm/mm]	No. of fatigue cycles performed by the splice, Lc [cycle]	Expected splice operating time, T_p [months]
1	14	0,35	177 858	7
2	15	0,35	212 656	8
3	16	0,35	251 346	10
4	17	0,35	294 079	12
5	18	0,35	341 003	13
6	19	0,35	392 260	15
7	20	0,35	447 991	18
8	21	0,35	508 335	20
9	22	0,35	573 425	22
10	23	0,35	643 394	25
11	24	0,35	718 371	28
12	24	0,40	426 945	17

This effect was shown in the example of a cold glue splice if it were operated on a conveyor in the "I" mine. The belt parameters are as follows: tensile strength 1600 kN/m, shear strength 3.5 kN/m^2, and joint delamination strength 14 kN/m. The splice modulus of elasticity is 18000 kN/m. In the last rows of the table, the value of the relative elongation of the adhesive bond has been increased by an additional value of 0.05 mm/mm. An increase in the parameter by 0.05 mm/mm caused a decrease in the fatigue life of the splice by as much as 290000 cycles, which shortened the splice operating time by 11 months.

The higher the rubber's tensile strength, the greater the splice's number of fatigue cycles and thus its working time (Fig. 3). Therefore, it should be aimed at ensuring that the rubber strength has the highest possible value. The analysis clearly shows that this parameter has a more minor impact on the splice's working time than the relative elongation of the adhesive bond.

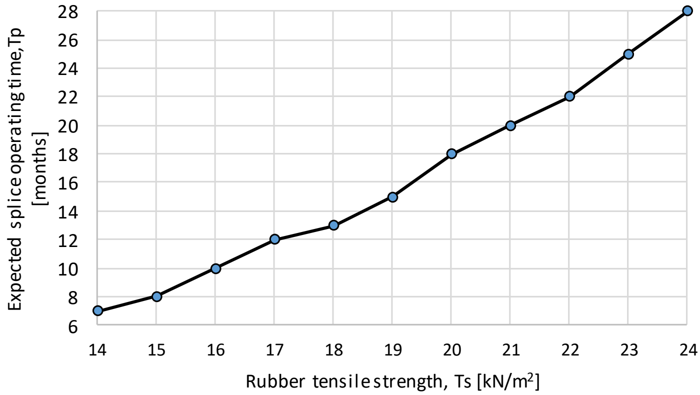

Fig. 3. Dependence of splice operating time on inter-ply rubber tensile strength (mine "I")

Table 5 presents the calculations of the effect of the number of drums on which the belt bends on the splices' operating time. Simulation calculations were performed using the example of a conveyor operating in the "IV" mine. The values of the parameters of both the belt and the joints entered into the calculations are constant. Only the change in the number of drums impacts the change in the splices' operating time – conveyor parameters in the "IV" mine: length 1005 meters, belt speed 2.5 m/s. The conveyor operates 20 hours a day and operates for 30 days a month. The simulation results show that the fewer the drums in contact with the belt, the longer the splice will operate. Adding a drum reduces the splice's operating time because the belt bends more often. This process accelerates the destruction of the splice, causing it to delaminate. Doubling the number of drums reduces the operating time of both splices twice. Therefore, it should be aimed at ensuring that the number of drums in contact with the belt is as tiny as possible.

Table 5. Results showing the splice operation time depending on the number of working drums on the example of the "IV" mine

No.	No. of drums on the conveyor, l_b [no.]	No. of fatigue cycles performed by the splice [no.]		Expected splice operating time, T_p [months]	
		Cold-glued, *Lc*	Vulcanized, *Nc*	Cold-glued	Vulcanized
1	3	178954	203358	22	25
2	4			17	19
3	5			13	15
4	6			11	13
5	7			10	11

Table 6 presents the calculated splice operating times in the four analyzed mines. The supplier of the belts for all mines was the same manufacturer, and they are the same type of belts (they only differ in width). The following assumptions were made in the calculations: belt strength 1600 kN/m, shear strength 3.5 kN/m^2, delamination strength 14 kN/m, belt elasticity modulus 19000 kN/m, rubber tensile strength 24 kN/m^2, the splice module has the same value as the belt module. All conveyors operate 20 hours a day, 30 days a month. The main factor influencing the splice operating time, in the case of constant belt and splice parameters, is the number of drums on which the belt is bent, the length of the conveyor, which determines the frequency of the belt bent on the drums, and the belt speed, which affects the time of its full rotation.

In Table 6, the last column shows the actual working times of the splices operating in mine conditions. These were hot-vulcanized splices. According to the analysis, the splice vulcanized in the “IV” mine should have worked for 21 months, but in actual conditions, it worked for 18 months. Such a slight difference is because a belt conveyor transports miners. As a result, the service, wanting to provide employees with the highest safety standards, pays special attention to the condition of the belt splices on the conveyor. In other mines, the simulation results of the splice working time, depending on the mine, differ from the actual data regarding the working time of the splice by between 3 and 8 months. These discrepancies result from the conditions in which the splice worked.

Table 6. Splices operating time in individual mines

Mine	Conveyor length, L_p [m]	Belt speed, v [m/s]	No. of fatigue cycles performed by the splice [cycle]		Expected splice operating time, T_p [months]		Real operating time, [months]
			Cold-glued, *Lc*	Vulcanized, *Nc*	Cold-glued	Vulcanized	
I	400	3.15			7	9	6
II	624	3.00			12	14	6
III	1410	3.15	181 558	225 466	19	23	18
IV	1005	2.50			17	21	18

The simulation of the splice working time does not consider belt operation disturbances that may lead to its damage (Bortnowski et al. 2022; Doroszuk et al. 2019; Andrejiova et al. 2020; Marasova et al. 2017; Rudawska et al. 2020; Kessentini et al. 2019). These belt conveyors only transport hard coal, so they are not as closely monitored as conveyors transporting crew (Kirjanów-Błażej et al., 2022).

The hot-vulcanized splice from the "IV" mine was expected to work for 21 months, but it worked for 18 months. If it were replaced with a cold-glued splice, which, according to the simulation, should have worked without failure for 17 months, its actual working time would be much shorter. The situation is similar in other mines. This can be summed up by saying that cold-glued splices work for a shorter time than hot-vulcanized splices, and therefore, they should be made only when it is not possible to make a vulcanized splice.

4. CONCLUSIONS

Conveyor belt connections made using the hot vulcanization method are more reliable and durable than those made using the cold gluing method. They are characterized by a much longer working time, which reduces their higher cost of production. Additionally, conveyors that work with the vulcanized splice can transport crews in mines. This allows for significant savings for mines, resulting from a faster time for miners to reach their workplace and a reduction in accidents related to their movement in the mine. In addition, it supports the crew's more efficient work.

Performing simulation calculations of the splice durability before it is made allows for selecting the appropriate belt and type of connection for the existing conveyor so that the splice can operate for as long as possible without any failures. If the mine knows how long the splice will be able to work on the conveyor, it can analyze whether it is profitable to buy a more expensive belt with better parameters. Using a more expensive but much more durable vulcanized splice allows, in some cases, a significantly longer operating time of the belt loop compared to a cold-glued splice. This allows the mine to reduce operating costs.

The key parameter influencing the working time of a splice made using the cold gluing method is the relative elongation of the adhesive bond. This parameter has the most significant impact on its durability. It depends on the proper selection of adhesive materials and the execution of the splice itself.

Comparing the simulation results of the splices' failure-free operation with the actual data obtained from the mines, it is visible that the splices could have operated longer. Depending on the mine, this is from 3 to 8 months. The simulation calculations did not consider sudden phenomena that could have occurred during the belt operation and the connection. It was assumed that the belt operation proceeded without disruptions, that the belt did not run off the conveyor, that it did not rub against the conveyor structure, etc. Each such phenomenon shortens its operating time. In hard coal mines, the operating conditions of conveyors are difficult, there is high humidity, and water appears in the transport corridors. Connecting in such conditions with high humidity and dust also affects its operational durability.

The most minor difference between a vulcanized splice's actual and predicted working times occurs in the "IV" mine. This is because the conveyor is constantly monitored, and its working conditions are constantly monitored because it transports people and must be safe in operation.

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