Mining Science, vol. 29, 2022, 165–178

www.miningscience.pwr.edu.pl

Mining Science

(Previously Prace Naukowe Instytutu Gornictwa Politechniki Wroclawskiej, ISSN 0370-0798)

ISSN 2300-9586 (print)
ISSN 2353-5423 (online)

Received March 26, 2022; Reviewed; Accepted September 21, 2022

EXAMINATION AND ASSESSMENT OF THE IMPACT OF WORKING CONDITIONS ON OPERATING PARAMETERS OF SELECTED CONVEYOR BELTS

Mirosław BAJDA*
Monika HARDYGÓRA

Faculty of Geoengineering, Mining and Geology, Wroclaw University of Science and Technology, Poland

Abstract: The effect of the operation of two textile-core conveyor belts, type B-1600 P-1600/5 8+4 H, which operated in one of the lignite mines, on their strength and operating parameters was determined. During the operation of the belts on the conveyor, the amount and type of spoil transported were recorded, as well as the belt's operating time. The results of tests on the strength parameters of the belts in operation were compared with the results of tests performed on the same belts before their operation.

Keywords: *belt conveyor, conveyor belt, textile belt, belt testing*

1. INTRODUCTION

Underground and open-pit mines face the problem of transporting excavated material (Bardziński et al. 2019; 2020). Transporting excavated material is a very high cost that the mine must bear. The European mining system is dominated by conveyor belt transport. These are the cheapest and most efficient transport systems, given the economic conditions in Europe. Throughout the transport cycle, the conveyor belt is subjected to many factors that affect its wear and tear (Król 2017; Doroszuk et al. 2019; Walker et al. 2020). These include factors that can occur suddenly such as puncturing the belt (Marasova et al. 2017), cutting or tearing it (Bortnowski et al. 2022), and those that occur during the entire life of the belt, i.e., abrasion of the belt covers due

* Corresponding author: miroslaw.bajda@pwr.edu.pl (M. Bajda)

doi: 10.37190/msc222910

to contact between their surfaces and the transported ore (Kirjanów-Błażej et al. 2022). In connection with the wear of a conveyor belt during its operation on a conveyor, the manufacturer of the belt is obliged to present its test results (Andrejiova et al. 2020), which show that it meets the values of the required strength parameters imposed by the customer. This applies to new belts. For economic reasons, mines try to use conveyor belts, which have already worked for a certain period of time and have been dismantled from the conveyors and placed in storage (Jurdziak 2000). They can be reused if their condition allows it (Blazej et al. 2022). Because of this, it is necessary to check how both the conditions of its operation and the time of its operation have affected its strength parameters (Rudawska et al. 2020).

Two types of conveyor belts are commonly used in lignite mines: steel cord belts and textile-core multi-ply belts. An analysis of the effect of the aging of steel cord belts under natural conditions on strength parameters was performed (Bajda and Hardygóra 2018). It shows that the belts lose their properties as a result of many years of use in the mine. However, they still have parameters at a high level that allow them to continue to be used (Bajda 2019). The key question, therefore, is whether multi-ply textile belts can still be used by a mine after many years of operation. To get an answer to this question, it is necessary to check how the time of operation under natural conditions affects their strength and operating parameters. To this end, tests were performed on the strength of the belt, and the adhesion strength between its elements was checked. It also investigated how the strength parameters and abrasion of the belt cover change.

2. RESEARCH METHODOLOGY

The effect of the operation of two textile-core conveyor belts, type B-1600, P-1600/5, 8+4 H, which operated in an open-pit lignite mine, on their strength parameters was studied. During the operation of the belts on the conveyors, the amount and type of ore transported were recorded, as well as the operating time of the belts. The results of testing the strength parameters of the belts in operation were compared with the results of tests performed on the same belts before their operation. The belt sections prepared for testing were tested for the hardness of the cover rubber on the running and carrying side, then the belt thickness and the thickness of the covers were measured. After that, suitable locations were selected on the belt from which samples could be taken for subsequent tests.

Before testing, the following samples were prepared:

- for testing adhesion strength between covers and core and between plies in the core,
- for testing the tensile strength of the full-thickness belt in the longitudinal and transverse directions,
- for testing abrasion resistance,
- for testing the tensile properties of the belt covers.

The tests were performed according to ISO standards at the accredited Belt Transport Laboratory of the Wrocław University of Technology (called LTT for short). The following laboratory tests of belts and rubber covers were performed:

– testing of adhesion strength between covers and plies and between plies, the test was performed according to the test method described in PN-EN ISO 252:2008,
– testing of the tensile strength of the full thickness belt in the longitudinal and transverse directions, the test was performed according to the test method described in PN-EN ISO 283,
– testing of elongation of the belt at the break as well as testing at an elongation of the force corresponding to 10% of the strength of the belt, the test was performed according to the PN-EN ISO 283 standard,
– testing of abrasion resistance of the cover rubber, according to PN-EN ISO 4649:2007 standard,
– testing of the tensile properties of the rubber, according to PN-EN ISO 37.

2.1. DESCRIPTION OF STUDY OBJECTS

The test object is two textile-rubber belts, type B-1600 P 1600/5 8+4 H, which were produced by two manufacturers. The belts are 1600 mm wide and have a nominal tensile strength of 1600 kN/m. The belts are constructed of a core with five polyamide-polyamide plies. Non-operated belts should meet the strength parameters specified in EN 14890:2013-06. Such belts should achieve a nominal tensile strength of at least 1600 kN/m, the thickness of the top cover should be a minimum of 8 mm, while the running cover should be 4 mm. The rubber of the belt covers of class H should achieve a minimum of 24 MPa tensile strength, and its elongation should not be less than 450%, while its abrasion should not be greater than 120 mm^3. The belts that are the subject of this study meet these requirements and the values determined in laboratory tests can be found in Table 1. Table 1, includes data on the year the belts were manufactured, how

Table 1. Description of the study objects

Belt designation		A-10	B-07
Working time on the conveyor [months and days]	overburden	–	34 months
	coal	–	2 months and 2 days
	both	73 months and 25 days	36 months and 2 days
The material being transported (tonnes]	overburden	2 738 000	4 216 000
	coal	7 622 000	90 000
	both	10 360 000	4 306 000
Conveyors		Overburden and coal	Overburden conveyor cooperating

	conveyor cooperating with one multi-bucket excavator	with two multi-bucket excavators, Collective conveyor transporting coal to the power plant

long they were operated on conveyors, the type of ore transported, as well as the designation of the conveyors on which the belts operated.

The belts operated on conveyors transporting both coal and overburden. The main difference between the belts was the length of time they operated on the conveyor and the weather conditions prevailing during this period.

The first subject of the study was belt number A-10, which operated for 6 years 1 month and 25 days on a coal overburden conveyor transporting both coal and overburden. From the time the belt was installed on the conveyor until it was removed, the belt transported a total of 10 360 000 tonnes of mixed ore, including 7 622 000 tonnes of coal and 2 738 000 tonnes of overburden.

The section of this belt taken for testing was approximately 1555 mm wide and 590 mm long. The thickness of the top cover ranges from 3.8 mm to 4.3 mm, while the thickness of the running cover ranges from 0.2 mm to 2.2 mm. The overall thickness of the belt is between 15.0 mm and 16.4 mm. The hardness of the top cover is 78–79 °ShA, while the hardness of the running cover is 78-81 °ShA. The belt is quite heavily worn, as can be inferred from the thicknesses of the covers and the change in belt width created by edge rubbing. A view of the belt is shown in Figure 1, where the locations from which the samples were taken for testing are indicated. As can be seen, the left side of the belt shows signs of abrasion and damage to the core plies, so this part of the belt could not be used for testing.

Fig. 1. Belt sample A-10, view from running cover side

The second object of study is a belt, numbered B-07, which operated for 3 years and 2 days on two conveyors and transported mainly overburden. It worked first on the overburden conveyor, which worked with two multi-bucked excavators. After 2 years and 10 months on the overburden conveyor, it transported 4 216 000 tonnes of excavated material. It was then removed and put on the gathering conveyor that transported coal to the power plant. During its 2 months and 2 days of operation, it transported 90 000 tonnes of coal. Over the entire period of its operation, it transported a total of 4 306 000 tonnes of ore.

The section of the belt to be tested was approximately 1525 mm wide and approximately 540 mm long. The thickness of the top cover ranges from 6.9 to 8.1 mm, while the thickness of the running cover is 2.4 to 2.9 mm. The overall thickness of the belt is between 16.5 and 17.7 mm. The hardness of the running cover as well as the carrying cover is 71-72 °ShA. The belt is quite heavily worn, as can be deduced from the thickness of the covers and the change in width through edge rubbing. The view of the belt from the running cover side is shown in Figure 2.

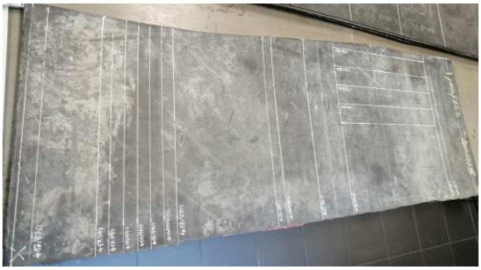

Fig. 2. Belt sample B-07, view from running cover side

When comparing the condition of the two belts, it can be seen that the greatest wear on the rubber, as well as damage, is on the running side of the belt, with belt B-07 appearing less worn (Fig. 2). Therefore, it can be assumed that the damage to the belts was not caused by excavated material, but by contact between the belt and the conveyor's structural components. The thickness of the bottom cover of the A-10 belt ranges from 0.2 to 2.2 mm. Due to the insufficient thickness of the cover, it was not possible to test the strength parameters, the abrasion resistance, and the adhesion force between the cover and the fifth ply of the belt core.

2.2. TEST OF STRENGTH AND ELONGATION OF THE BELT

The test was performed according to the test method described in EN ISO 283 by preparing paddle-shaped (type B) belt samples. A test sample of the belt, cut from the full thickness of the conveyor belt, was placed in the grips of the testing machine and

Fig. 3. LabTest 6.100 test stand

stretched at a speed of 100 mm/min until it broke. During the measurement, the stretching force and elongation of the belt were recorded using a video-extensometer. The elongation was measured at a force value that corresponded to 10% of the actual strength of the belt at the moment of breaking. Figure 3 shows the LabTest 6.100 tensile strength belt testing machine, which consists of a 100 kN force sensor located on a sliding machine frame and a video extensometer.

The video extensometer used to measure the elongation of the specimen, together with the testing machine, is connected to a computer that records the tensile force and elongation of the specimen.

2.3. TEST OF ADHESIVE STRENGTH BETWEEN BELT ELEMENTS

The test of adhesion strength between the belt elements was carried out by PN-EN ISO 252:2008, using method B, with the INSTRON 4464 testing machine (Fig. 4). Method B, involves separating every second belt element from each other. The average value of the force required to delaminate the covers from the core, as well as each ply from each other, is determined using a testing machine with a constant cross-beam speed of 100 mm/min.

Fig. 4. Sample of belt during delamination

Each test specimen should be a strip of a belt of rectangular cross-section with evenly trimmed edges, with a width of (25±0.5) mm and a minimum length of 200 mm to allow delamination over a section of not less than 100 mm. The top cover was delaminated first from the first ply (On-1p), the second ply from the third (2p-3p), and the fourth ply from the fifth (4p-5p). The order is reversed when testing the second specimen, i.e., the running cover is delaminated first from the fifth ply (Ob-5p), the fourth ply from the third (4p-3p), and the second ply from the first (2p-1p). In this way, the strength of adhesion between all elements of the belt is tested.

2.4. ABRASION RESISTANCE TEST

The abrasion resistance test was carried out in accordance with EN ISO 4649:2007 method A, using an apparatus with a rotating drum (Figure 5). The test determines the volume loss of the rubber cover as a result of the abrasion of the sample, on an abrasive cloth of known granulation. During the test, the sample is held stationary and its entire surface is in contact with the abrasive surface. The test result is expressed as a relative volume loss of the rubber being tested. It is therefore necessary to determine the specific density of the rubber. The density of the rubber was determined using a hydrostatic method by weighing the rubber sample in air and in distilled water of known density and temperature.

Fig. 5. Apparatus with rotating drum, including sample holder

The dimensions of the specimens for the rubber abrasion resistance test are a cylinder of 16 ± 0.2 mm diameter and a minimum height of 6 mm. Where the thickness of the rubber is less than 6 mm, it is possible to cut a specimen with a belt core. The minimum rubber thickness for the abrasion resistance test shall not be less than 2 mm.

2.5. TESTING THE STRENGTH PROPERTIES OF RUBBER

Tensile testing of the rubber was carried out in accordance with EN ISO 37, using an INSTRON 4464 machine, testing paddle-shaped rubber specimens of type 1A. The length of the test section for this type 1A specimen is 20 ± 0.5 mm. The rubber specimens are stretched at a constant speed of 500 mm/min until they break. During the test, the force values and corresponding elongations are recorded. A 500N force sensor was used in the test, as well as a mechanical extensometer to measure the elongation of the rubber.

Fig. 6. INSTRON 4464 strength testing machine,
and installed in the grips a rubber sample

Figure 6 shows the test rig, and the rubber sample mounted in the self-clamping jaws, on which the mechanical extensometer is clamped.

3. TEST RESULTS

The results of the belt geometry measurements, such as width, overall thickness, and cover thickness, are shown in Table 2. This table includes the values that are required for this type of belt, but it should be remembered that these relate to belts that are new and have not been in operation. As far as the requirements are concerned, the belts have reached the required values prior to mining. Belts A-10 and B-07 are quite heavily worn. As a result of the operation of the belt, both the top and the running cover have significantly reduced in thickness. The width of the belts has also decreased, mainly through edge wear.

Table 2. Belt measurement result

Tested parameter, unit	New belt		Belt after operation		Required values
	A-10	B-07	A-10	B-07	
Running cover thickness, mm	4.1	4.6	0.2÷2.2	2.4÷2.9	min. 4
Top cover thickness, mm	8.0	8.7	3.8÷4.3	6.9÷8.1	min. 8
Belt thickness, mm	22.7	23.3	15.0÷16.4	16.5÷17.8	–
Belt width, mm	1600	1600	1555	1525	1600 ± 5

Table 3 compares the results of testing the strength parameters of in-service and new belts. This table additionally provides information on the strength parameters required for P1600/3 8+4 H type belts [PN-EN 14890:2013-06]. It should be noted that the requirements relate to the test results of non-used belts, but are nevertheless an important source of reference.

Table 3. Summary of test results

Tested parameter, unit	New belt		Belt after operation		Required values
	A-10	B-07	A-10	B-07	
Tensile strength of the belt in the longitudinal direction, kN/m	1869	1825	1417	1455	min. 1600
Belt elongation with a load of 10% of the nominal strength, %	1.9	2.0	1.7	2.4	max. 4.0

Belt elongation at break, %	25.0	–	15.6	18.9	–
Tensile strength of the belt in the transverse direction, N/mm	496	453	471	409	–
The delamination strength between the plies in the core, N/mm	11.0	10.7	10.3	6.8	min. 5.0
Delamination strength between rubber covers and core, N/mm	8.8	7.3	7.9	6.0	min. 4.5
Abrasion, mm^3	117	88	153	106	max. 120
Hardness, °ShA	62	65	78÷79	71÷72	65 ± 5
Tensile strength of rubber, MPa	24.2	24.1	14.2	14.5	min. 24
Rubber elongation at break, %	519	466	199	300	min. 450

The elongation of the belt at the core break and the tensile strength of the belt in the transverse direction are parameters that are not mandatory for belt manufacturers. There are no specific requirements for their values. However, it is extremely important for users of conveyor belts to know how the values of these parameters change as
a result of the belt's use. Too great a change in their values can be taken into account when planning the joint of an in-service belt and can rule out such a solution.

4. TEST RESULTS ANALYSIS

Tests were carried out on the strength parameters of two belts of the same type - new and after operation under the conditions of one of the lignite mines in Poland. The values obtained were compared with each other and the results of the comparisons were related to the values obtained for the new belt. Table 4 shows the results for belt A-10 and Table 5 shows the results for belt B-07. The "–" indicates a decrease in values concerning the results obtained for the new belt.

Table 4. Comparison of the results of the A-10 belt tests

Tested parameter, unit	Belt A-10			
	new	after operation	difference	% new belt
Tensile strength of the belt in the longitudinal direction, kN/m	1869	1417	–452	–24.2
Belt elongation with a load of 10% of the nominal strength, %	1.9	1.7	–0.2	–10.5
Belt elongation at break, %	25.0	15.6	–9.4	–37.6
Tensile strength of the belt in the transverse direction, N/mm	496	471	–25	–5.0
The delamination strength between the plies in the core, N/mm	11.0	10.3	–0.7	–6.4

Delamination strength between rubber covers and core, N/mm	8.8	7.9	–0.9	–10.2
Abrasion, mm^3	117	153	36	30.8
Hardness, °ShA	62	78.5	16.5	26.6
Tensile strength of rubber, MPa	24.2	14.2	–10.0	–41.3
Rubber elongation at break, %	519	199	–320	–61.7

Table 5. Comparison of the results of the B-07 belt tests

Tested parameter, unit	Belt B-07			
	new	after opera-tion	difference	% new belt
Tensile strength of the belt in the longitudinal direction, kN/m	1825	1455	–370	–20.3
Belt elongation with a load of 10% of the nominal strength, %	2.0	2.4	0.4	20.0
Belt elongation at break, %	–	18.9	–	–
Tensile strength of the belt in the transverse direction, N/mm	453	409	–44	–9.7
The delamination strength between the plies in the core, N/mm	10.7	6.8	–3.9	–36.4
Delamination strength between rubber covers and core, N/mm	7.3	6.0	–1.3	–17.8
Abrasion, mm^3	88	106	18	20.4
Hardness, °ShA	65	71.5	6.5	10
Tensile strength of rubber, MPa	24.1	14.5	–9.6	–39.8
Rubber elongation at break, %	466	300	–166	–35.6

Analysis of the results presented in Tables 5 and 6 shows that, after operating, the belts reach lower values for all parameters tested except hardness and abrasion-resistance. It should be noted that an increase in the abrasion resistance value results in a less abrasion resistant belt. Also, the hardness of the belt covers is higher which can be explained by the aging of the rubber as a result of the actual atmospheric conditions that accompanied the operation of the belt.

After the operation, the conveyor belts reached a tensile strength value well below the required minimum, i.e., 1,600 kN/m. Compared to the values obtained for new belts, belt A-10 reached a strength value 24.2% lower and belt B-07 reached a value 20.3% lower.

By analyzing the results of the adhesion strength between the elements of the in-service belt, it can be seen that both the adhesion value between the textile plies of the belt core and between the covers and the core are decreasing. However, the results obtained for both belts are greater than the required minimum, which is 5.0 kN/m for the adhesion force between the core elements and 4.5 kN/m between the cover and the core.

The results of the abrasion resistance test of in-service belts seem to be confirmed in practice if the thickness of the top covers is taken into account. The A-10 belt has a cover almost twice as thick as those of the B-07 belt. The A-10 belt operated for more than six years on the conveyor and transported about 10.3 million tonnes of ore, while the B-07 belt operated for three years and transported 4.3 million tonnes of ore. The A-10 belt transported both overburden and coal. The overburden alone was transported by belt A-10 in the amount of 65% of that of belt B-07. Since in the conditions of an open-pit mine, the overburden is the material that is most responsible for the abrasion of the top cover, and the amount of overburden carried by the belts is different, the difference in the loss of the top cover thickness was most likely due to the difference in the abrasion of the belts. The abrasion resistance of belt A-10 has a value of approximately 44% higher compared to belt B-07, which means that it is less resistant to abrasion. As a result, the thickness of the top cover of belt A-10 has decreased to between 3.9 mm and 4.2 mm (average 4 mm) compared to an initial thickness of 8 mm. The thickness of the top cover of belt B-07 decreased by an average of about 0.5 mm as a result of service, reaching values between 6.9 and 8.0 mm. The abrasion resistance of the rubber cover in class H should not exceed 120 mm^3. Despite years of use, belt B-07 still meets this requirement (106 mm^3), while belt A-10 exceeds this value by more than 27%.

The loss in thickness of the belt running covers was most likely due not to the difference in abrasion resistance of the rubber, but also to the conditions of the belt movement over the idlers, which caused the rubbing of the covers and other damage seen in Figures 1 and 2.

The test results for the tensile strength of the rubber as well as the elongation in tension reached values that deviated significantly from the required minimum values. The required tensile strength of the rubber in class H is 24 MPa, while the results for both belts are lower by approximately 40%. The same applies to the elongation of the rubber, which is lower than the required value of 450% for tape A-10 by about 33% and for tape B-07 by about 55%.

5. CONCLUSIONS

The analysis of the results of laboratory tests of multi-ply conveyor belts showed that their exploitation in lignite mine conditions harmed most of the strength parameters tested, lowering their values. The studies showed that:

– After use, the belts recorded a similar decrease in tensile strength in the longitudinal direction. For the A-10 belt, this is a loss of 452 kN/m, i.e., 24% compared to the value obtained for the new belt. The B-07 belt reached a value lower by about 20% (370 kN/m) of the strength obtained for the new belt;

- The high abrasion value of the cover of the A-10 rubber belt can be seen by observing the belt sample visually. The running cover was worn down to the belt core in places, while the thickness of the top cover compared to its thickness before the start of operation was almost half as much. The degradation of the running cover was most likely accelerated by its wearing off against idler sets and other elements of the conveyor, as well as negatively affecting the conditions accompanying the operation of the conveyor in the open area;
- Abrasion of the top cover took place only through its contact with the transported excavated material. The difference in abrasion resistance between the tested belts was about 44%, while the difference in the average loss of the top cover thickness was greater. The cover of the A-10 belt wore out as much as 8 times faster compared to the B-07 belt. Even if we take into account the fact that the A-10 belt worked for over 6 years on the conveyor, and the B-07 belt for only 3 years, and that the A-10 belt transported twice as much ore (coal + overburden), the rate of wear of the A-10 belt top cover is way too fast. The abrasion resistance of the A-10 belt in laboratory tests showed a value of 153 mm^3 against the required maximum value, which is 120 mm^3. If the belt retained the abrasion parameter below 120 mm^3, it can be assumed that the wear of the carrier cover would be much slower. This is evidenced by the test results of the B-07 belt, which during over 3 years of operation on the conveyor reduced the thickness of the top cover by an average of 0.5 mm, even though it transported over 1 478 000 tons of overburden more;
- The value of tensile strength and elongation of the cover rubber of both belts is much lower compared to new belts. A decrease in these values by approx. 40% was observed compared to the required minimum values (24 MPa and 450%). This may be due to the working conditions of the belt in the open area in the mine and the influence of atmospheric conditions, including negative and positive temperatures and sunlight. However, despite this, the decrease in the value of these parameters is still too high. An additional influence on the test results could have been the fact that as a result of exploitation, the rubber showed signs of wear in the form of small cuts and micro-cracks. As a result of these failures, the rubber in laboratory tests could break at a lower tensile force;
- Both belts retained the high adhesive strength between the plies and between the plies and the covers.

Summing up the conclusions, it should be emphasized that they concern the tests of small belt sections, which were slightly over 0.5 m long. To fully illustrate the impact of belt operation conditions and time on the decrease in their strength and operating parameters, it would be necessary to perform tests on a larger number of samples, which should be taken from several places along the entire length of the belt loop, which sometimes reaches several kilometers in length.

ACKNOWLEDGEMENTS

The authors would like to thank the accredited Conveyor Belt Transportation Laboratory for providing samples of belts for testing and test stands where the tests presented in this article could be performed.

REFERENCES

ANDREJIOVA M., GRINCOVA A., MARASOVA D., 2020, *Analysis of tensile properties of worn fabric conveyor belts with renovated cover and with the different carcass type*, Eksploatacja i Niezawodność – Maintenance and Reliability, 22, 472–481; http://dx.doi.org/10.17531/ein.2020.3.10

BAJDA M., 2019, IOP Conf. Ser.: Earth Environ. Sci., 221, 012098, DOI: 10.1088/1755-1315/221/1/012098.

BAJDA M., HARDYGORA M., 2018, *The influence of natural ageing processes on the strength parameters of steel cord conveyor belts*, International Journal of Mining, Reclamation and Environment, DOI: 10.1080/17480930.2018.1436030.

BARDZINSKI P., JURDZIAK L., KAWALEC W., KRÓL R., 2020, *Copper ore quality tracking in a belt conveyor system using simulation tools*, Natural Resources Research, 29 (2), 1031–1040, DOI: 10.1007/s11053-019-09493-6.

BARDZINSKI P.J., KROL R., JURDZIAK L., 2019, *Empirical model of discretized copper ore flow within the underground mine transport system*, International Journal of Simulation Modelling, 18 (2), 279–289, DOI: 10.2507/IJSIMM18(2)473.

BŁAŻEJ R., JURDZIAK L., KIRJANÓW-BŁAŻEJ A., BAJDA M., OLCHÓWKA D., RZESZOWSKA A., 2022, *Profitability of Conveyor Belt Refurbishment and Diagnostics in the Light of the Circular Economy and the Full and Effective Use of Resources*, Energies, 15 (20), 1–15, DOI: 10.3390/en15207632.

BORTNOWSKI P., KAWALEC W., KRÓL R., OZDOBA M., 2022, *Types and causes of damage to the conveyor belt – review, classification and mutual relations*, Engineering Failure Analysis, 140, DOI: 10.1016/j.engfailanal.2022.106520.

DOROSZUK B., KRÓL R., 2019, *Analysis of conveyor belt wear caused by material acceleration in transfer stations*, Mining Science, 26, 189–201, DOI: 10.5277/msc192615.

JURDZIAK L., 2000, *The conveyor belt wear index and its application in belts replacement policy*. Proceedings of the Ninth International Symposium on Mine Planning and Equipment Selection, Athens, 6–9 November 2000, A.A. Balkema, 589–594.

KIRJANÓW-BŁAŻEJ A., BŁAŻEJ R., KOZŁOWSKI T., RZESZOWSKA A., 2022, *Innovative diagnostic device for thickness measurement of conveyor belts in horizontal transport*, Scientific Reports, 12 (1), DOI: 10.1038/s41598-022-11148-1.

KRÓL R., 2017, *Studies of the durability of belt conveyor idlers with working loads taken into account*, Paper presented at the IOP Conference Series: Earth and Environmental Science, 95 (4), DOI: 10.1088/1755-1315/95/4/042054.

MARASOVA D., AMBRISKO L., ANDREJIOVA M., 2017, *Examination of the process of damaging the top covering layer of a conveyor belt applying the FEM*, Measurement, 112, 47–52, DOI: 10.1016/j.measurement.2017.08.016.

RUDAWSKA A., MADLEŇÁK R., MADLEŇÁKOVÁ L., DROŹDZIEL P., 2020, *Investigation of the effect of operational factors on conveyor belt mechanical properties*, Appl. Sci., 10, 4201.

WALKER P., DOROSZUK B., KRÓL R., 2020, *Analysis of ore flow through longitudinal belt conveyor transfer point*, Eksploatacja i Niezawodność, 22 (3), 536–543, DOI: 10.17531/ein.2020.3.17.