

Assessment of the Conveyor Belt Strength Decrease due to the Long Term Exploitation in Harmful Conditions

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ABSTRACT

Bucket conveyors are widely used in various industrial sectors due to their efficiency in material transport. However, like any machinery, they are susceptible to degradation during operation, leading to a decrease in performance and an increase in the risk of failure. Therefore, research was conducted to understand the impact of operation on bucket conveyor belts. In the study, specimens were prepared from different locations and sections of the belt to investigate potential differences in material properties and strength. A series of mechanical tests, including a static tensile test, were conducted to assess the material strength. The results of the research revealed differences in mechanical properties among specimens from different locations and belt sections. Furthermore, potential damages that may occur with incorrect handling were unveiled. These findings are crucial for industrial practices, providing a better understanding of factors influencing the durability and efficiency of bucket conveyor belts.

Keywords: conveyor, belt, conveyor belt strength, wear, tensile test.

INTRODUCTION

Industrial conveyor belts, crucial for efficient load transfer, can be made from various materials and fiber types, with the matrix of flexible thermoplastic polymer and synthetic rubber influencing the mechanical properties of the belt, while structural reinforcement is achieved through steel, nylon, aramid, or carbon fibers, tailored to the required strength and flexibility. Experimental analyses of the mechanical properties and strength of these belts provide insight into their behavior under different loads and conditions. In industry, roller, belt, and chain conveyors are among the popular methods of internal material handling, facilitating the efficient movement of products over short and long distances in production processes and warehouses. Conveyor belts, being the most popular choice, serve as a key component in

many industries owing to their numerous advantages, such as simplicity of construction, flexibility, and high efficiency [1]. Conveyors of this type enable different types of materials to be moved efficiently over considerable distances. This is especially true for bulk and granular materials. One of the varieties of belt conveyors are conveyors in which buckets and carriers are additionally mounted on the belts, which even allows vertical transport. Conveyor belts consist of many components, but the conveyor belt is the key component. Damage to the conveyor belt can generate significant downtime costs for the conveyor system, as the belt is at risk of damage due to the operating conditions and contact with the material [2]. The strength of the belt depends on various factors, such as the bonding technology, material ageing or dynamic loads, as well as its capacity over a long period of time [1].

Research on conveyor belts is not only limited to practical applications. Various methods and technologies, such as reliability theory or computer simulations, are used in scientific articles to analyze their performance and behavior under different conditions [3]. Reliability models of conveyor belts are used to identify weaknesses in conveyor systems and optimize their performance [4, 5]. Another challenge is puncture damage, e.g. in open-pit mines. In order to solve this problem, new structural solutions such as impact racks or disc springs have been developed, which not only reduce repair costs, but also have a positive impact on the environment in and around the mine [6]. Researchers use advanced analytical methods like fuzzy data analysis and numerical techniques to monitor conveyor belt conditions. These methods help assess wear and tear, optimizing maintenance and replacement strategies [7, 8]. The introduction of new technologies, such as virtual models and dynamic analysis, allow to designed more efficiently and reliable conveyor belts. Using methods such as computed tomography or tension tests, the condition of the internal structure of belts can be monitored and their mechanical properties analyzed [9–11]. Studying the materials used in manufacturing conveyor belts is crucial. Analysis of the mechanical properties of fabrics and rubbers, as well as testing of the strength of metal-rubber joints, allows for the improvement of production processes and the selection of optimal materials [12, 13]. The conclusions drawn from these studies carry significant implications for enhancing the performance and reliability of conveyor belts across diverse industries. Investigating their behavior under various loads and conditions paves the way for innovative solutions, potentially revolutionizing the conveyor industry and contributing to operational efficiency improvements. The research also focuses on analyzing the rare breaks that occur in ‘continuous’ sections of conveyor belts. The researchers identify ‘sensitive points’ in the design, particularly in the transition section of the belt. The influence of the width of the specimens on the strength of the belts is presented, illustrating the forces in the transition section and analyzing the instability of the loads in this area. A theoretical model has been created that is applicable to both steel cord and textile webbing. This model shows that after replacing the belt with another of a different type and elasticity, the loads become more unstable [14, 15]. Another study presents experimental measurements of selected properties of tubular conveyor belts that

have suffered dynamic damage. In addition to the results of the experimental measurements, an analysis of the internal structure of the conveyor belt using computed tomography was used. The aim of the presented paper is to show changes in the physical and mechanical properties of conveyor belts subjected to dynamic damage and to analyze their internal structure – the conveyor belt shell – using a non-structural method of analysis [16]. When analyzing the phenomenon of breaks in conveyor belts, the focus was on multi-layered belts during bending, stretching and peripheral force transmission from the drum. Using elasticity theory, equations describing the stress state were developed. Experimental studies have confirmed the effect of tension force on the wear resistance of the belt. Methods for calculating the strength of conveyor belts have been presented [17]. Material fatigue is one of the main causes of damage and failures, both in the case of austenitic steel, which is often used as a load-bearing material in belts, and in conveyor belts themselves. Research on fracture surface topography and the impact of load variability is crucial for understanding material fatigue mechanisms and optimizing their durability under various working conditions. Such studies contribute to expanding our knowledge of material strength and ensuring better performance in industrial practice [18, 19]. These articles contribute to the development and improvement of conveyor belts. Through research, innovation and understanding of their properties, it is possible to create more reliable, efficient and cost-effective solutions for bulk and granular material handling and other areas of industry where conveyor belts play an important role [1–17, 19]. This article specifically addresses the issue of conveyor belt strength degradation. However, it’s important to note a lack of specific research on the impact of operation on strength loss, and this publication aims to fill that gap in the literature. In the framework of experimental research, the focus is on precisely determining the impact of load on the decrease in belt strength. The ultimate goal is not only experimental material degradation but also demonstrating the impact of improper handling on the potential for damage and predicting the behavior of the conveyor belt under various loading conditions during transport or assembly.

MATERIALS AND METHODS

The material used in the study was a bucket conveyor belt with the designation EP800/5,

indicating that the belt had five layers made of a polyamide-polyester fabric. The belt's width was 345 mm, and its strength was specified at 800 N/mm. The belt was employed for the vertical transport of loose asphalt material, with bucket spacings approximately 350 mm apart. The belt operated for approximately 10 years, posing a potential risk of degradation, which was the primary focus of the analysis. Figure 1 depicts sections of the belt designated for sample collection and an experiment involving chain transport, termed as a simulation of incorrect installation technique. After removing the buckets and contaminants, the belt was prepared for the subsequent procedures discussed in the following section.

In order to identify the structure of the composite belt, an elemental piece was taken from the belt from which the rubber layer was removed revealing the geometry and nature of the weave (Fig. 2).

Microscopic observations were carried out using digital microscope Leica dvm6 (Keyence). In order to obtain more information of surface morphology the high-resolution Scanning Electron Microscope Supra 35 (Zeiss), equipment with SE (secondary electrons) detector was used. Additionally, chemical composition analysis in the micro areas was evaluated using an energy-dispersive X-ray detector (EDX, EDAX Trident XM4). Before microscopic observation of fracture surfaces, specimens were subjected to sputtering with a thin conductive silver-palladium layer using putter coater SCD050 (BAL-TEC). Figure 3 presents analyzed composed materials.

It can be observed, that the composite material has a layered structure - layers of rubber (matrix material) are separated by the layer of fibers.

SEM micrographs in Figure 4 present surface morphology and EDS plots of the analyzed composite material, including rubber (Figs. 4a–c) reinforced with fibers (Figs. 4d–f). Some cracks in the rubber were visible. Additionally, the existence of single particles, and also particle agglomeration areas for the rubber were observed. The microchemical analysis presents indicate the presence of carbon, silicon, and magnesium. It was shown, that single fibers consist of many smaller fibers (in the article called sub-fibers), which are parallel to each other and regularly distributed in the main fiber. The size of sub-fibers also was regular and the mean diameter was $24.2 \pm 0.3 \mu\text{m}$. However, the existence of many highly oxidized solid aggregates on the sub-fibers was observed. Based on the EDS analysis it was found that the fibers consist mainly of carbon.

Wear degradation of the conveyor belt has been performed based on the tensile test. Based on ISO 527-4 [20] standard and considering the quantity and type of material subjected to testing, along with the provisions of the specialized ISO 283 [21] standard, a geometric shape for the specimens was proposed (Fig. 5). This procedure aimed to adapt the shape of the specimens to the requirements of ISO 527-4 and take into account the conditions under which the material would be tested. The proposed geometric shape of the specimens was developed to ensure compliance



Figure 1. View of two parts of a bucket elevator constituting the sections of a conveyor intended for mechanical testing



Figure 2. Belt section with selected geometry and weave character



Figure 3. Surface morphology in digital microscopy

with the standards while simultaneously reflecting the conditions in which the material will be in service. The detailed representation of the sample shapes is presented in Figure 5.

Numerous traces of transmission belt structure damage were found on the surface of the evidence provided for examination. Damage was caused, among other factors, by wear and tear as well as mechanical interference likely resulting from improperly conducted transport operations. Due to this, it was decided that three groups of three individual specimens would be made. The aforementioned specimens were appropriately

placed on the examined fragment of the belt, as depicted in Figure 6. The specimens have been described in Table 1.

Group P (Fig. 6) consisted of specimens taken from between the feeder buckets in the transverse direction. Group U and W (Fig. 6) populations were obtained from the longitudinal direction, with one group taken from the central part of the belt with no visible blemishes on the working (measuring) part, while the second group was obtained from a location bearing utility damage from the buckets (Fig. 7, 8), located in the central measuring part of the sample. This allowed us to

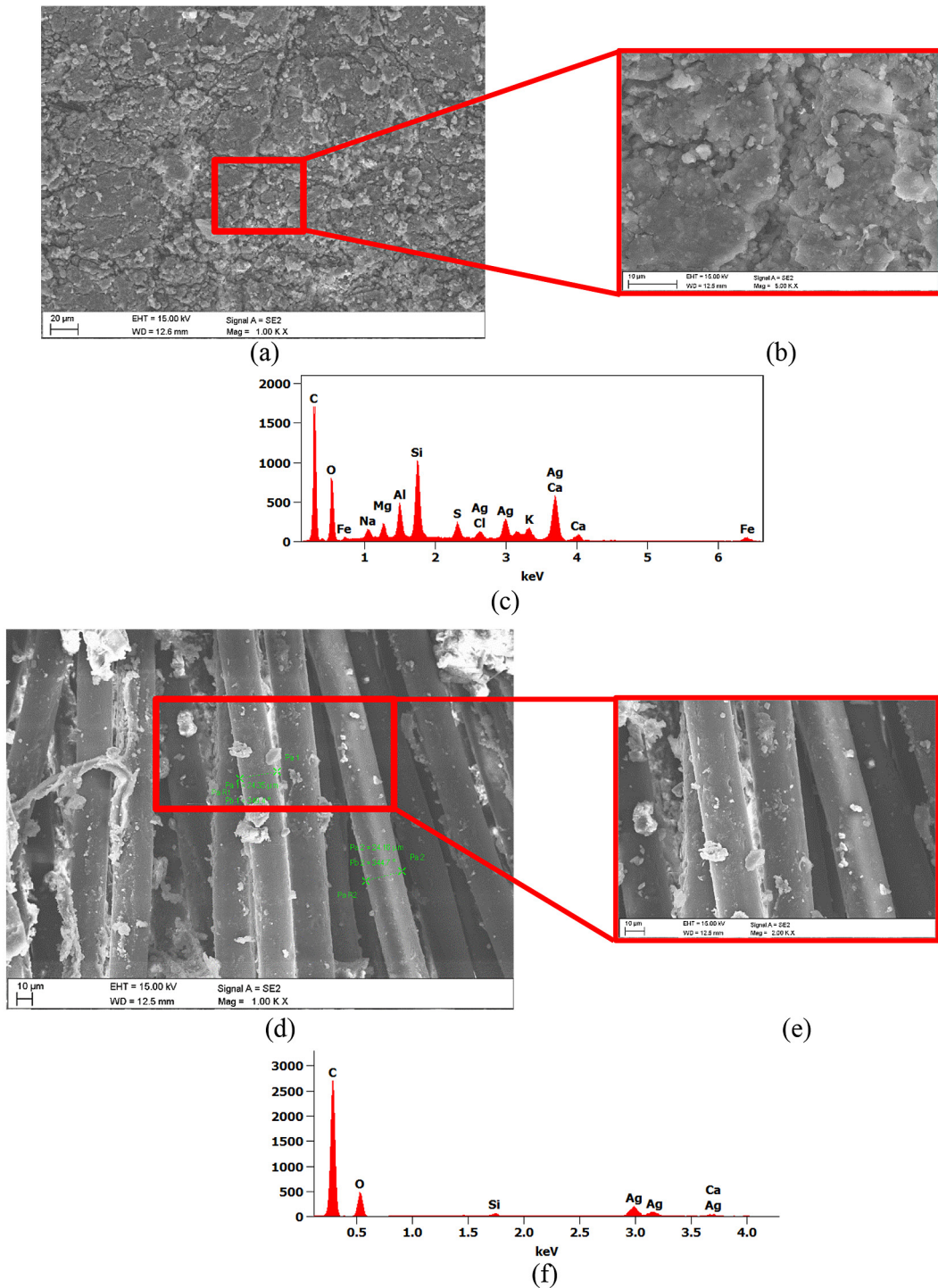


Figure 4. Results of SEM analysis (a) and (b) rubber, (c) EDS analysis for selected area, (d), (e) fibers 1 and (f) EDS analysis for selected area

determine the degree of mechanical damage to the belt by the percentage decrease in strength in this area. Utilizing the water-jet cutting technique, specimens were chosen for conducting uniaxial strength tests (Fig. 8). To prepare the machine for testing, an additional test specimen labeled as K1 was cut out. The specimens underwent air drying and were conditioned for a period of 14 hours

at 25 °C. From time to time the conveyors belt must be disassembled and assembled again. This process is often performed with use of chains or bars which may lead to create a damage in the belt structure. Therefore, the research with use of the special holding fixture was performed to simulate the way the belt is transported. It aimed to replicate the effect of fastening components, such as

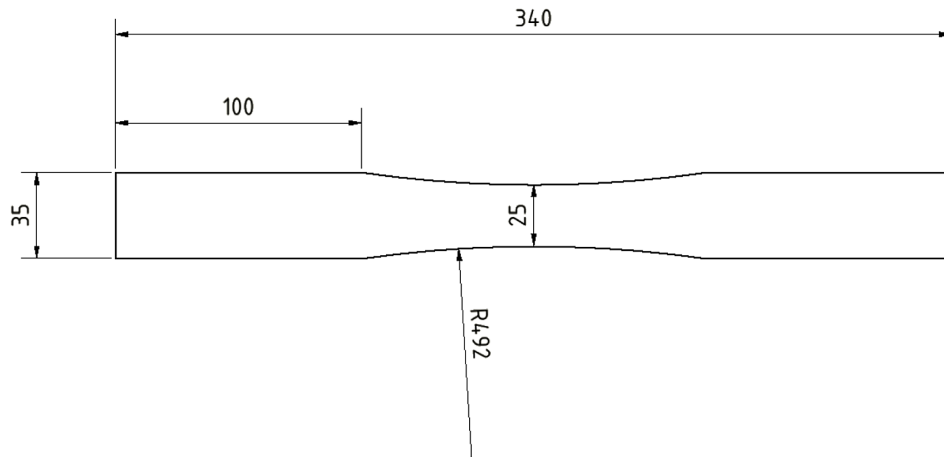


Figure 5. Geometry of tensile test specimens



Figure 6. Specimens groups (U, W, P) for strength tests



Figure 7. View of the damage location beneath the bucket

chain links, exerting pressure on the bucket conveyor belt during manipulative operations associated with its assembly or disassembly. For this purpose, a design was developed based on steel semi-finished parts, which were connected to a

section of the belt free from signs of mechanical. The force applied in the experiment corresponded to the weight of the belt, aiming to verify whether the belt would not tear during machine retooling operations. Chains are frequently used

Table 1. Designation and description of the specimens

Symbol	Meaning	Description
U	Specimens group 1	Specimens taken longitudinally from a site with damage
W	Specimens group 2	Specimens taken longitudinally from a location without damage
P	Specimens group 3	Specimens taken in the transverse direction
K1	Technical specimen	



Figure 8. Three groups, specimens designed to perform a tensile test

for handling and transporting conveyor belts. The utilization of chains, and consequently the specific arrangement of links, significantly influences the belt's deformation. In areas where the most substantial deformations occur, particularly at belt corners, links may embed themselves, cutting into the drive belt, causing damage, and concentrating stress. Severe deformation occurs where links press against the belt on its sides. As a result of the conducted experiment, an adverse impact of the chain on the belt surface was observed. Due to the dynamic nature of the chain, composed of interconnected links capable of arbitrary movements relative to each other, and in the context of the static susceptibility of the belt, which, as a result of relative motion associated with increased load, may lead to visible damage, especially in the region of the largest displacements. To conduct this type of test, a system capable of simulating high loads was necessary. In the experiment, a four-column servo hydraulic testing machine was used (with a column diameter of approximately 10.16 cm – MTS 311.31), and the gripping mechanism was provided by hydraulic wedge grips (MTS model 647). The machine is capable of generating a load of 1 MN. A test speed was set as 50 mm/min. Test was conducted until reaching the maximum force of 50 kN. Additionally, the ambient temperature was 19 °C with an air humidity of 74%. It was fitted with a steel belt retaining device. And on the underside,

a component for mounting the chain. This made it possible to simulate the loading conditions when lifting the belt. As mentioned earlier, such lifting is potentially degrading. This test was used to verify this hypothesis.

RESULTS

On the basis of the conducted tests it was proved that the specimens show lower strength (ability to carry loads) in relation to the nominal strength (declared by the manufacturer). The probable reason could be the operational wear of the structure of the conveyor belt. The slight differences in test results between specimens taken from the same direction but with damage to the base of the conveyor buckets in the measuring section are due to damage to the surface layer (facings) of the belt without breaking the continuity of the braid of the conveyor belt. The strength of the specimen taken from the conveyor belt was determined on the basis of a tensile test. Information on the width of the specimens, the force at break and their strength is presented in Table 2. The obtained results were compared with the catalog data of the belt. According to the belt designation, the nominal strength of the belt should be 800 N/mm. Comparison of the information obtained from the tensile test and the catalog data indicates a decrease in the strength properties of



Figure 9. Belt during the lifting test with use of the special fixture

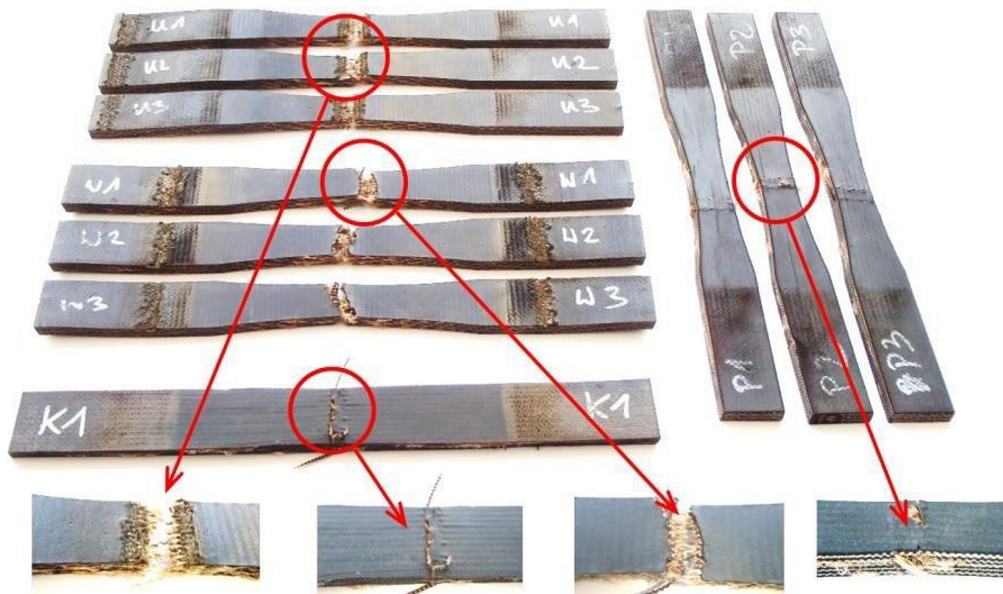


Figure 10. Damage to specimens after tensile testing

the belt during operation. Specimens taken longitudinally (which do not have a defect approaching from the base of the bucket in the measuring range) exhibit a strength decrease of about 3% compared to the nominal value. Specimens with damage at the measuring range have an average strength of 701 N/mm. Therefore the decrease of 12.5% relative to the nominal value is observed. The damages observed on these specimens originate from external sources, such as wear caused by friction from the buckets, which can be

particularly detrimental to the entire system. The obtained results indicate the necessity of more frequent inspections and monitoring of belt conditions, especially in applications where they are used with additional elements, such as buckets, which can cause mechanical damage. Additionally, it is worth noting that specimens taken longitudinally show varied strength reductions, with greater declines in areas under the buckets, which may hinder the detection of such damages without disassembling the belt apparatus. The

strength of specimens taken from the transverse direction is much lower than from the longitudinal direction. This may be due to the use of reinforcing fibers, a different type of weave than in the longitudinal direction. The strength in the transverse direction is much less because the longitudinal direction is its main load carrying direction. As a result of the experiment, a negative effect of the chain on the belt surface was observed. Due to the nature of the chain work which consists of interconnected links which can move freely in relation to each other and due to the static susceptibility of the belt which, due to the relative movement occurring as a result

of the load increase, causes visible damage in the form of abrasions observable particularly in the area of the largest displacements (Fig. 11). However, these damages are not strictly degrading in structure and have a noticeable effect on the mechanical properties. Due to the cooperation of the steel links of the chain with the rubber surface of the belt, the friction force between the cooperating elements increases simultaneously as the load increases, and due to extensive deformations of the belt and considerable relative displacements of the chain, shearing of the rubber coating of the belt occurs, but without violating the structure of the composite.

Table 2. Strength of specimens taken from the conveyor belt

Sample	Width [mm]	Breaking load [N]	Strength [N/mm]
W1	24.1	18230	756.4
W2		20470	849.4
W3		17420	722.8
Average	24.1	18710 ± 1289.97	776.2 ± 53.547
U1	23.9	17100	715.5
U2		15900	665.3
U3		17260	722.2
Average	23.9	16520 ± 606.923	701 ± 25.391
P1	23.9	8400	351.5
P2	23.9	8430	352.7
P3	24.2	8860	366.1
Average	24.0	8560 ± 210.132	356.8 ± 6.618



Figure 11. Damage formed in the analyzed belt during the lifting test

CONCLUSIONS

Results from the conducted tests confirm a reduction in the conveyor belt's strength compared to the nominal value declared by the manufacturer. The likely cause of this phenomenon may be the operational wear of the conveyor belt structure. Differences can be observed in the specimens taken from the longitudinal direction, particularly between those with damage caused by the steel bucket and those without.

The overall assessment indicates that the conveyor belt has lost its original properties, with inspections revealing numerous damages, especially underneath the buckets. The results confirm a reduction in the conveyor belt's strength compared to the nominal value, with a 3% (approximately 24 N on average) reduction in strength for fatigued belts and a 12.5% (approximately 99 N on average) reduction for those damaged beneath the buckets. Detailed findings are provided in Table 2.

While lifting with chains generally functions, there is observed damage occurring on the edges of the belt, which may lead to its weakening. The results suggest that such connection with the buckets exposes the belt to damages, potentially leading to its rupture under load. Regular inspection of such belts is recommended to prevent accidents that may harm individuals, as well as to avoid unexpected failures and incidents.

REFERENCES

- Mazurkiewicz, D. Analysis of the ageing impact on the strength of the adhesive sealed joints of conveyor belts. *Journal of Materials Processing Technology*. 2008; 208(1–3): 477–485. <https://doi.org/10.1016/J.JMATPROTEC.2008.01.012>
- Bortnowski, P., Kawalec, W., Król, R., Ozdoba, M. Types and causes of damage to the conveyor belt – Review, classification and mutual relations. *Engineering Failure Analysis*. 2022; 140, 106520. <https://doi.org/10.1016/J.ENGFAILANAL.2022.106520>
- Yan, C., He, X. Model and dynamic simulation of belt conveyor. *Proceedings - 2010 International Conference on Intelligent System Design and Engineering Application, ISDEA 2010*. 2010; 1: 949–951. <https://doi.org/10.1109/ISDEA.2010.331>
- Wang, H., Dai, J. X. Research on the reliability of underground coal mine belt conveyor system. *2011 2nd International Conference on Mechanic Automation and Control Engineering, MACE 2011 – Proceedings*. 2012; 7636–7639. <https://doi.org/10.1109/MACE.2011.5988818>
- Ahmadi, S., Moosazadeh, S., Hajihassani, M., Moomivand, H., Rajaei, M.M. Reliability, availability and maintainability analysis of the conveyor system in mechanized tunneling. *Measurement*. 2019; 145: 756–764. <https://doi.org/10.1016/J.MEASUREMENT.2019.06.009>
- Gondek, H., Pokorny, J., Bohác, D., Luzar, L. Reduction of conveyor belt piercing on conveyor belts at surface mines. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 2020-August(1.2)*; 227–232. <https://doi.org/10.5593/SGEM2020/1.2/S03.029>
- Jurdziak, L. The conveyor belt wear index and its application in belts replacement policy. *Mine Planning and Equipment Selection 2000*. 2018; 589–594. <https://doi.org/10.1201/9780203747124-112>
- Ambriško, L., Marasová, D., Grendel, P. Determination the effect of factors affecting the tensile strength of fabric conveyor belts. *Eksploatacja i Niezawodność*. 2016, 18(1), 110–116. <https://doi.org/10.17531/EIN.2016.1.14>
- Du, D., Li, H., Zhu, C., He, Q. Virtual prototype modeling and starting method of belt conveyor. *Applied Mechanics and Materials*. 2012; 148–149, 879–882. <https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMM.148-149.879>
- Fedorko, G., Molnár, V., Živčák, J., Dovica, M., Husáková, N. Failure analysis of textile rubber conveyor belt damaged by dynamic wear. *Engineering Failure Analysis*. 2013; 28: 103–114. <https://doi.org/10.1016/J.ENGFAILANAL.2012.10.014>
- Fedorko, G., Molnár, V., Michalík, P., Dovica, M., Kelemenová, T., Tóth, T. Failure analysis of conveyor belt samples under tensile load. *Journal of Industrial Textiles*. 2019; 48(8): 1364–1383. https://doi.org/10.1177/1528083718763776/ASSET/IMAGES/LARGE/10.1177_1528083718763776-FIG20.JPEG
- Barburski, M. Analysis of the mechanical properties of conveyor belts on the three main stages of production. *Journal of Industrial Textiles*. 2016; 45(6): 1322–1334. https://doi.org/10.1177/1528083714559567/ASSET/IMAGES/LARGE/10.1177_1528083714559567-FIG7.JPEGDobrot
- D. Adhesion degradation of rubber and steel insert for conveyor belts. *Journal of Adhesion Science and Technology*. 2013; 27(2): 125–135. <https://doi.org/10.1080/01694243.2012.701511>
- Woźniak, D., Hardygóra, M. Aspects of selecting appropriate conveyor belt strength. *Energies*. 2021; 14(19). <https://doi.org/10.3390/EN14196018>
- Tojiyev, D.R., Isomidinov, P.A., Alizafarov, A.B. Strength and fatigue of multilayer conveyor belts under cyclic loads. *Turkish Journal of Computer and*

- Mathematics Education. 2021; 12(7). Bajda, M., Hardygóra, M. Analysis of Reasons for Reduced Strength of Multiply Conveyor Belt Splices. *Energies* 2021; 14(5): 1512. <https://doi.org/10.3390/EN14051512>
16. Woźniak, D., Hardygóra, M. 2021. Aspects of Selecting Appropriate Conveyor Belt Strength. *Energies* 2021; 14(19): 6018. <https://doi.org/10.3390/EN14196018>
17. Macek, W., Robak, G., Žak, K., Branco, R. Fracture surface topography investigation and fatigue life assessment of notched austenitic steel specimens. *Engineering Failure Analysis* 2022; 135: 106121. <https://doi.org/10.1016/J.ENGFAILANAL.2022.106121>
18. Ilanković, N., Živanić, D., Zuber, N. The Influence of fatigue loading on the durability of the conveyor belt. *Applied Sciences* 2023; 13(5): 3277. <https://doi.org/10.3390/APP13053277>
19. ISO 527-4:1997 - Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites. (n.d.). Retrieved December 6, 2023, from <https://www.iso.org/standard/4595.html>
20. ISO 283:2007 - Textile conveyor belts — Full thickness tensile strength, elongation at break and elongation at the reference load — Test method. (n.d.). Retrieved December 6, 2023, from <https://www.iso.org/standard/38394.html>