

BADANIA WYDŁUŻALNOŚCI I WYTRZYMAŁOŚCI ZŁĄCZY KLEJONYCH W ASPEKTCIE OPRACOWANIA KOMPUTEROWEGO SYSTEMU MONITOROWANIA ICH STANU W CZASIE PRACY PRZENOŚNIKA TAŚMOWEGO

TESTS OF EXTENDABILITY AND STRENGTH OF ADHESIVE-SEALED JOINTS IN THE CONTEXT OF DEVELOPING A COMPUTER SYSTEM FOR MONITORING THE CONDITION OF BELT JOINTS DURING CONVEYOR OPERATION

Artykuł prezentuje wyniki przeprowadzonych badań laboratoryjnych wydłużalności i wytrzymałości typowych złączy klejonych taśm przenośnikowych. Celem badań było poznanie parametrów wytrzymałościowych złączy w celu określenia wytycznych dla projektowanego układu monitorującego, którego zadaniem będzie przeciwdziałanie nieprzewidzianemu zerwaniu taśmy w obszarze każdego złącza wykonanego na trasie przenośnika taśmowego. Do badań laboratoryjnych wykorzystano typowe złącze wykonane i eksploatowane w kopalni Lubelski Węgiel „Bogdanka” S.A.

Słowa kluczowe: *przenośnik taśmowy, taśma przenośnikowa, złącza klejone, wytrzymałość złączy, komputerowy system monitorowania stanu złączy.*

The paper presents the results of the laboratory tests conducted on the physical elongation and strength of typical adhesive-sealed joints of conveyor belts. The tests were aimed at examining the strength parameters of the joints to define some guidelines for a monitoring system designed to prevent unpredicted belt ruptures in the area of each joint occurring throughout the belt conveyor route. In the laboratory, typical joints were tested as manufactured and as used in the Lubelski Węgiel “Bogdanka” S. A. coal mine.

Keywords: *belt conveyor, belt transportation reliability, adhesive-sealed joints, joint strength.*

1. Introduction

According to Żur's definition [23], a belt conveyor is a limited range, continuously moving transport facility that carries material on the belt surface, between two belts or inside a belt. There are a number of belt conveyor designs which, when expanded into a transport system, form one of the most crucial elements used by mining companies (for both underground and opencast operations), chemical, food, power companies, etc. The conveyor transport, being in many cases a principal element of extended transport systems, must comply with numerous requirements. According to Antoniak [4], the latter includes the high reliability of a single conveyor in terms of prolonged daily working time, low operating costs, easy relocation and elevated belt strength. In particular, the latter element of the belt conveyor structure plays an important role since the belt cost frequently accounts for 40-50% of the total equipment cost. The conveyor belt is exposed to a number of impairments of different type and origin.

According to Antoniak [1-4], the conveyor belt should be chosen to ensure it can carry the highest tensile forces that occur under different conveyor operation conditions, and have a suitable reliability and safety rating. When purchasing a belt, the user receives an appropriate certificate that states the type and number of the belt, the belt minimum lengthwise tensile strength, the belt maximum percentage elongation at a load equal to 10% of the belt rated strength the minimum percentage

value of the belt elongation at failure etc. The actual values of the above strength parameters are in this case compared with their equivalents, in conformity with respective requirements. This follows from the fact that conveyor belts have a number of requirements to meet in terms of durability, strength, combustibility, etc. When analysing typical designs of conveyor belts, Żur [23] underlines the fact that the belt transmits lengthwise forces necessary to overcome movement resistances, and therefore it must be characterised by a sufficient lengthwise and crosswise strength to enable the absorption, without any damage all loads occurring at the output drop in the dumping equipment and while carrying the material over the roller sets. Transferring high forces from the conveyor drive to the belt through the drive wheels is equally important. The belt must also be flexible enough to settle into a trough shape, and yet at the same time it must not be so flabby that it folds between the rollers. Certainly, it must also be sufficiently durable and resistant to punctures, mechanical damage and abrasion, while being insensitive to weather and atmospheric conditions [1, 9, 23]. Antoniak [1, 4] assesses the requirements to be met by typical conveyor belts, and concludes by emphasising the requirement for very high strength of the belt segment joints.

In recent years, a number of studies have been carried out [1-3, 11, 12] aimed at selecting suitable designs and strengths of belts and their elements. It is equally important to achieve improvements to the strength parameters of the belts. In consequence, individual studies focus on the conveyor belt structure

(the material of the belt, the type and material of the core, the thickness of facings and rims), belt production methods, and belt acceptance tests. The studies also include suitable storage and transport methods. Considerable attention is also paid to rheologic models, for example, aimed at mapping belt strength parameters under dynamic loading or formatting the adhesive layer in adhesive-bonded joints and adhesive-mechanical joints [7, 8].

On the other hand, much less attention is paid to conveyor belt joints. The following conditions must be met to achieve the required value of joint strength: the tensile strength of joined belts should not be lower than the nominal strength, the joined belts should be of the same type, the joined belts should have two or more but equal number of fittings, and the joints should be made free of faults. In practice, joints are made in compliance with in-company instructions or the adhesive manufacturers' recommendations, and these very often differ. The conditions designed to ensure high strength and durability are not always complied with, either, which is mainly a consequence of performing such works in underground conditions of limited comfort. Therefore, as described in the literature [1, 4, 11], in order to achieve a joint with the highest strength, only belts from the same manufacturer should be used, of the same type and made of the same fittings in terms of the material strength, the method of weaving and the technological processing. The strength of the resulting joined belts is lower than the nominal level with different extendability or number of fittings.

A significant volume of the research work conducted in Poland and abroad is restricted to methods of joining belts, the technologies used, the types of mechanical and adhesive-sealed joints as well as the assessment of the impact of various factors on joint durability or strength [4, 11]. One commonly overlooked fact is that although typical belt joints (e.g. those made with the cold bonding method) have numerous advantages, they have also equally numerous faults. Bonding technologies are considered to be the most suitable for making joints as they ensure maintaining belt continuity, have high strength and durability, and, moreover, they mate well with the rollers and drive wheels of the conveyor system. Some important shortcomings include a low tenacity when compared with the belt itself. Although adhesive-sealed joints are relatively inexpensive, they are characterised by a significant diversity in strength, which results from different temperature and humidity conditions prevailing during joint production. The actual accuracy of the joint itself is important, as joints are frequently made in underground mine conditions that can hardly be called comfortable.

As a result, belt joints frequently break during conveyor operation without any preceding symptoms that might indicate an imminent occurrence of such an impairment. Although some effort is aimed at raising the durability and reliability of conveyor belt joints; nevertheless, users of belt conveyors, while having at their disposal sophisticated drive structures, control systems and operation parameter monitoring systems, are left on their own as regards the problem of unpredictable belt joint ruptures. Some unpredictable belt ruptures may result from a mechanical blockage of the belt, a side descent or wheel contamination, and such situations can be observed by the operating personnel and prevented if reacted to quickly enough. Nevertheless, this is not an effective method of counteracting joint rupture. It should be remembered that a rupture is not only a threat to the personnel, but it also means significant economic

losses resulting from a long stoppage of not only a single belt conveyor (the damaged one) but also of the whole transport system that the conveyor forms part of.

As demonstrated above and in previous publications [12÷14], during research studies into belt conveyor construction and the design of supporting elements, insufficient attention is paid to conveyor belt joints although their strength significantly affects the durability and reliability of the whole transport facility and even the whole system that includes the belt conveyors. For this reason, for several years research work has been carried out at the Lublin Technical University aimed at analysing the strength properties of adhesive-sealed joints from the point of view of developing a system monitoring joint condition during belt conveyor operation. Relevant laboratory test results are presented in this paper.

2. Conveyor belt joints and joint strength

Conveyor belts are manufactured in sections of specific lengths and so delivered to the customer. Belt users join all the sections when installing the conveyor to obtain an endless run. During the operation, new belts and those transferred from other, no longer exploited facilities are joined (relocation). During the life of a belt it may be constantly lengthened or shortened, depending on the mining method used (from borders, to borders). Conveyors are moved to new locations and constructed from different belt segments. In consequence, the number of belt joints is subject to continuous change, and hence difficult to control. The joints should have the highest possible tensile strength and the lowest number of joints along the conveyor route. In mining conditions, these requirements are frequently difficult to meet, especially since the number of belt joints continuously increases during an individual belt's life. The above conditions must be met for the joint strength to achieve the required value. The conditions are partly related to the tensile strength of the joined belts, the belt type, the number of fittings and the lack of any manufacture defects.

Typical fabric/rubber belts are joined using one of the following three methods: hot vulcanisation, room temperature vulcanisation (bonding) as well as by means of mechanical connecting elements. Mechanical belt joints can be separable or inseparable, and must have a relative strength of not lower than 60% of the belt nominal tensile strength. Vulcanised and adhesive-sealed joints of fabric/rubber belts are made on the same joint structures, utilising gradual overlap joints [1, 4, 10]. According to Antoniuk [4], the theoretical strength of such a joint compared with the nominal belt strength is 67% for three fittings, 75% for four fittings, 80% for five and 84% for six. According to provisions of the standard [17], the tensile strength of a belt with such a joint should be:

$$t_{zr\ pw} \geq 0.85 \cdot t_{zr\ n} \cdot \frac{z-1}{z} \quad (1)$$

where z is the number of fittings.

It is also possible to determine the strength loss of the belt caused by joining its segments (known as strength loss in the belt joint). The loss value is specified by the respective DIN standard [15], depending on the type of core fittings and the joint type.

Adhesive technologies are considered to be the most appropriate methods of making joints since they guarantee ma-

intaining belt continuity, result in high strength and durability and, moreover, allow mating well with the conveyor rollers and wheels. On the other hand, significant shortcomings of these types of technology include a low tenacity when compared to the belt itself. Adhesive-sealed joints are relatively cheap; however, they are characterised by a significant dispersion caused by different temperature and humidity conditions that prevail during joint production, and accuracy of joint alignment itself is difficult to achieve. A consequence of these factors is that belt joints frequently rupture during conveyor operation without any preceding symptoms that might indicate an imminent occurrence of such an impairment. A conveyor stopped due to a belt rupture in the joint area is certainly undesirable, not only for economic reasons but also in view of the necessity to maintain the continuity of deliveries of the mined materials. For that reason, the Lublin Technical University, together with the company Lubelski Węgiel Bogdanka S.A., being the most modern and most innovative Polish coalmine, commenced the tests of strength and extendability of conveyor belt joints. The tests were partly aimed at analysing belt conveyor operation parameters that have an impact on frequent failures resulting from belt ruptures, as well as at developing an appropriate system for monitoring the equipment operational conditions and related automatic control to eliminate any critical situations. Another important test objective was to analyse the durability of various types of conveyor belt joints in order to enhance the joint quality or to develop modifications in joint execution technology without any loss in the flitting strength. Additionally, it was decided to analyse the reasons for manufacturing faults in joints and to compare the properties of adhesive materials applied from the point of view of their resistance to delamination and shearing.

In the context of constructing a computer system for monitoring conditions of adhesive-sealed conveyor belts, it was also important to assess the rupturing force value as well as to examine the rupture mechanism itself and to observe the joint behaviour at the moment of imminent permanent damage to the joint. An initial analysis of the conveyor belt strength and the durability of the joints made with the bonding method was combined with the above-described laboratory tests to enable us to propose the following research thesis:

The elongation of conveyor belt joints at the rupture moment depends on the properties of the belt itself (including the minimum admissible belt elongation at rupture) as well as on the quality of the adhesive-sealed joint achieved. Therefore, it is possible to monitor the joint elongation during the conveyor operation, while at the same time determining the critical value of the elongation when it ceases to be a dynamic elongation related to changeable operating conditions and instead becomes a value signalling an imminent joint rupture.

3. Laboratory tests of conveyor belt joints

Conveyor belt joints are usually tested in laboratory conditions using static or dynamic methods. The static methods consist in determining the tensile strength of a belt sample with a joint at an attempted rupture. The dynamic methods consist in applying a pulsating load to the belt sample with a joint by passing it through two turning wheels. The conditions for testing conveyor belts joints are specified in respective standards [15-21]. However, the tests are rather difficult to conduct since they require the use of special equipment, including level testing machines capable of rupturing a real size sample of a joint with a belt with a relatively high elongation value at rupture.

The laboratory tests [5, 6] conformable with the above objective started with an assessment of the strength and extendability of textile/rubber belts as applied by the company Lubelski Węgiel "Bogdanka" S.A. which cooperated in the test works with the Lublin Technical University. The tests included:

- measurement of the joint elongation value at the rupture time,
- measurement of the whole sample elongation (adhesive-sealed joint + belt) at rupture,
- progress of the joint elongation with a load till the rupture time, in compliance with the standard requirements,
- progress of the whole sample elongation (adhesive-sealed joint + belt) with a load till the rupture time, in compliance with the standard requirements,
- determination of the rupture force.

The laboratory tests involved the use of three belt joints. They were marked as I, II and III. The first two joints were new and made according to internal recommendations, while joint number III had been used previously for over two months in underground conditions on a typical wall haulage conveyor. The joints supplied for the tests had the following dimensions: width 1200 mm, length 1900 mm (joints I and II) and width 1200 mm and length 2800 mm (joint number III). The tested belt joints were made with the cold bonding method with the use of a four-flitting belt.

According to requirements of the PN-C-94147 standard [19], samples 200 mm wide were to be cut off from the joint for tensile strength tests. The test sample length was 1900 mm with slight deviations from that dimension. To ensure the same testing conditions, the length of all samples was equalised to 1900 mm. Five samples (marked as I/1 to I/5 etc.) were cut off from each joint. The dimensional markings assumed are shown in fig. 1. The laboratory tests were carried out on a ZP-40 testing machine. The samples were mounted in the testing machine jaws with a steady distance between the jaws of $L_z=1270$ mm being maintained. The stretching speed was 100 mm/min.

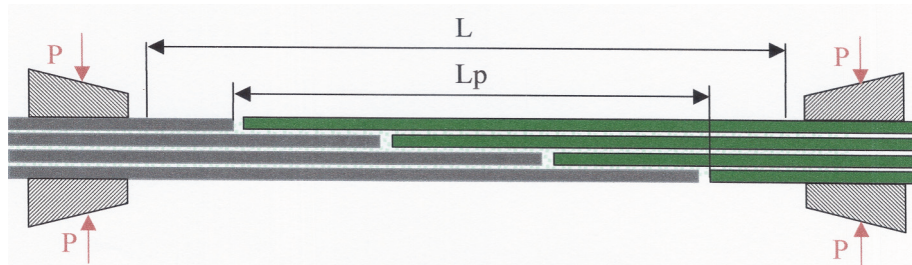


Fig. 1. Dimensional markings of the conveyor belt joints tested [5, 6]

The stretching progress was registered by the testing machine provided with appropriate software, and the L_p joint elongation was measured with a digital video camera placed over the joint butt from the side of the immovable jaw of the tensile testing machine. The butt line was marked on the belt cover and a millimetre gauge attached on the line of the second joint butt indicating the size of the joint elongation, which in turn was registered by the video camera simultaneously with the size of the force stretching the joint [22].

This enabled a recording of elongations of the both measured sizes simultaneously with the force gauge indications. Table 1 presents results of the laboratory tests. An example diagram of a test sample rupture (fig. 2) presents on the abscissas axis the sample length increase as measured by the tensile testing machine jaw travel. This value does not correspond to the actual sample elongation due to a partial pushing out of the samples from the clamping jaws.

A direct measurement of the total elongation of the joint and the belt, important from the point of view of determining the best location for monitoring system markers in the actual conditions, would not be possible due to the insufficient length of the tested samples. The length was 1900 mm instead of the required minimum of 2200 mm (joint length + 2 additional sections 600 mm each). In connection with the above, additional extendability measurements of the belts themselves (ϵ_r) were carried out with stresses corresponding to rupture stresses of individual belt joints. Then we calculated the total sample length increase $\Delta L_z = \Delta L_p + \Delta L_r$ in millimetres as well as ϵ_z as a percentage. The assumed length L_z amounts to 1270 mm. The results obtained are presented in table 2. We have also decided that in future the results will be verified by subsequent tests of full size samples.

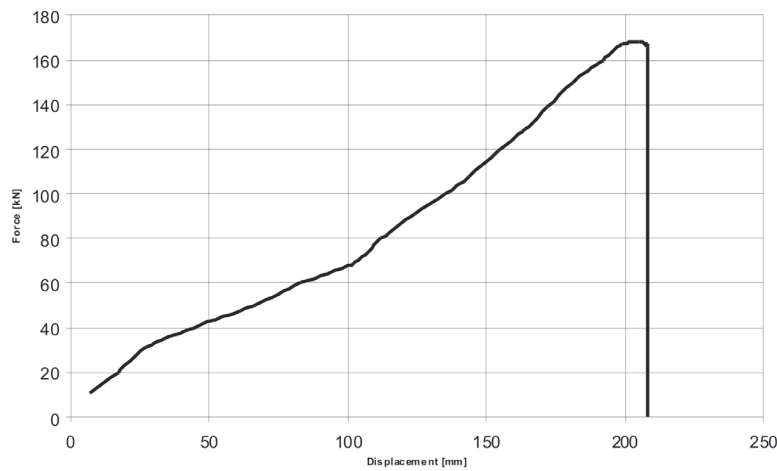


Fig. 2. Diagram of an example test sample rupture

Tab. 1. Results of adhesive-sealed joint strength and extendability tests

Sample number	I/1	I/2	I/3	I/4	I/5	II/1	II/2	II/3	II/4	II/5	III/1	III/2	III/3	III/4	III/5
Sample width, B [mm]	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Breaking force, F [kN]	167.2	189.8	203.7	167.9	186.4	187.1	161.1	174.4	169.4	192.2	139.8	176.4	165.1	152.2	184.8
Tensile strength, R [kN/m]	836.0	949.0	1018.5	839.5	932.0	935.5	805.5	872.0	847.0	961.0	699.0	882.0	825.5	761.0	924.0
Tensile strength, R_s [kN/m]	915.0					884.2					818.3				
Initial length of the joint, L_p [mm]	995.0					1002.0					922.0				
Length gain, ΔL_p [mm]	199	208	213	201	205	230	218	225	219	240	174	190	182	171	184
Length gain, ΔL_s [mm]	205.2					226.4					180.2				
Elongation of the tested length at break up, ϵ_p [%]	20.6					22.6					19.5				

Tab. 2. Results of strength and extendability tests of adhesive-sealed joint and belt sections

Joint number	I	II	II
Belt extendability, ϵ_t [%]	19.8	19.4	18.5
Total length, L_z [mm]	1270	1270	1270
Belt length outside the joint, L_r [mm]	275	268	348
Length increase, ΔL_r [mm]	54.4	52.0	64.4
Section total elongation, ΔL_z [mm]	259.6	278.4	244.6
Section total elongation, ϵ_{tz} [%]	20.4	21.9	19.2

4. Final conclusions

The results of the laboratory tests give some information on the analysed joint from the point of view of its strength and the data can be used to obtain on the theoretical strength of the adhesive-sealed joint. They also form a significant confirmation of the research thesis regarding the concept of monitoring the conveyor belt joint elongation under mining conditions in order to prevent unpredicted joint ruptures during conveyor operation. The theoretical strength of an adhesive-sealed joint for four flittings [4] is 75% of the belt rated strength. In the course of the laboratory tests, the results obtained were slightly lower than the theoretical values. The analysed samples tensile strength ranged from 50% to 57 % of the belt nominal length-wise tensile strength, with the lowest value obtained for sample no. III, which had been in use for two months prior to the tests. Consequently, the resulting low value (50%) might have resulted from partial wear of the belt, although the result obtained was not particularly affected by that fact since the values obtained in the tests of the new samples were similar (several percent higher).

Slightly better results were obtained in case of percentage elongation at rupture. They ranged from 19.5% to 22% for the joint sample tested, giving values much higher than the minimum belt material elongation at rupture - which should amount to 10% according to the requirement. At the same time, the values for the exploited belt and the new ones were nearly the same. This is proof of the good maintenance of the strength parameters of the belts and joints in spite of their being intensively used in mining conditions for several-months.

A significant value (from the point of view of the designed monitoring system) is the actual percentage elongation at rupture for the joint segment together with the adjacent belt material. This follows from the necessity to indicate a site for future installing of the monitoring system markers as well as determining the boundary values for alarm signals. If a marker has to be installed in a joint area the joint strength may be significantly reduced. Installation of markers in the area outside the joint would be much more comfortable and, additionally, would allow the differentiation of installation sites to facilitate a subsequent identification of joints. In the tests, the percentage elongation of the measure joint length (joint + belt sections outside the joint) at rupture was slightly lower than the percentage elongation of the joint itself, which is a simple consequence of the difference in the tensile strength between the joint area and the joint area

with additional belt sections on both sides. However, the values obtained did not differ much and were mutually proportional; they ranged from 19.5% to 22% for the joint and from 18.2% to 21.9% for the joint measured together with belt sections on both sides of the joint.

The laboratory tests produced some interesting information on the extendability and strength of conveyor belt joints as required for determining alarm signal values of the future monitoring system. The aim of the system will be to prevent belt ruptures in the joint area through a continuous measurement and assessment of length changes of each joint, irrespective of the joint type. However, the studies conducted so far have to be continued and supplemented to obtain a more comprehensive understanding of the subject. It is necessary to carry out laboratory tests according to an analogous program for other types of belts and other types of joints, including those made of new belts as well as joints with mechanical reinforcements, if only for the purpose of comparison. It is also indispensable to verify the results obtained in real operation conditions and the effect of a dynamic type of load.

However, considering the commonness of the application of belt conveyors in the industry as well as the absence of effective monitoring and control systems to prevent equipment failures resulting from belt joint ruptures, one can presume that the results of this research work and that of the subsequent implementation work will not only contribute to extending the knowledge and experience as regards belt conveyor operation, but they will also help to reduce the losses caused by the downtimes resulting from unpredicted failures.

The continuation of the conducted research and development work is aimed not only at constructing a suitable computer system for monitoring the conveyor belt joints elongation, but also at transforming the system into an intelligent machine, capable of unaided reaction to changing operating conditions and eliminating the conditions causing belt ruptures through predicting possible future operation parameters and their consequences. The intelligent system, when properly designed and specified on the basis of actual measured data, will be assigned with the task of making decisions on stopping the facility, changing its operating parameters or signalling the necessity to replace or strengthen a joint. In other words, automatically selected operating parameters will serve as equipment protection against occurrence of critical conditions. The system will function on the basis of a dynamic object control system based on the neuron control model.

The research work financed with the means of the Polish State Committee for Scientific Research in the years 2007-2011 as a research project

5. References

1. Antoniuk J. Underground transport facilities and system in coalmines. Poland: Śląsk Publishers, Katowice 1976.
2. Antoniuk J. Monitorowanie, kontrola i sterowanie procesów transportowych w górnictwie podziemnym. Maszyny Dźwigowo-Transportowe 2001; 1.
3. Antoniuk J. The development of belt conveyors and conveyor systems till the year 2010 in Relation to the Growing Mining Concentration. Mechanizacja i Automatyzacja 2001; 1.
4. Antoniuk J. Belt Conveyors. Introduction to the Theory and Calculations. Poland: Publishing House of the Silesian Technical University, Gliwice 2004.
5. Badania właściwości wytrzymałościowych złącza klejonego ze wzmocnieniem mechanicznym. Sprawozdanie nr LTT/02/05 Laboratorium Transportu Taśmowego Instytutu Górnictwa Politechniki Wrocławskiej (materiały niepublikowane).

6. Badania wytrzymałości i wydłużalności połączeń taśm tkaninowo-gumowych. Sprawozdanie nr Z-4/04/04 Laboratorium Transportu Taśmowego Instytutu Górnictwa Politechniki Wrocławskiej (materiały niepublikowane).
7. Czowniuk JW, Matwijkeno WA. Analytical dependences for determining parameters of adhesive-rivet joints. *Technologia i Automatykacja Montażu* 1994; 2: 38-40.
8. Czowniuk JW, Matwijkeno WA. The rheological model and the mechanism for adhesive layer constituting in adhesive and adhesive-mechanical joints. *Technologia i Automatykacja Montażu*; 1994; 2: 35-38.
9. Desowski A. A guide to conveyor belt use. Poland: Zakłady Gumowe Górnictwa, Bytom 1999.
10. Mining PVC belts – A directory and guidebook. Poland: Bydgoskie Zakłady Przemysłu Gumowego, Bydgoszcz 1994.
11. Hardygóra M, Komander H. The strength of multi-flitted joints of conveyor belts. *Przegląd Górniczy* 1998; 2: 10-13.
12. Mazurkiewicz D. Monitoring the condition of adhesive-sealed belt conveyors in operation. *Eksploatacja i Niezawodność - Maintenance and Reliability* 2005; 3: 41-49.
13. Mazurkiewicz D, Computer system for monitoring the condition of conveyor belt joints. *Mechanizacja i Automatykacja Górnictwa* 2006; 4 (423): 14-22.
14. Mazurkiewicz D. Analysis of the ageing impact on the strength of the adhesive sealed joints of conveyor belts. *Journal of Materials Processing Tech.* 2008; 208: 477-485.
15. Standard DIN 22110. Testing methods for conveyor belt joint; determination of time strength for conveyor belt joint; (dynamic testing method).
16. Standard DIN 22110-2. Testing methods for conveyor belt joints – part 2: endurance running tests, determination of running time belt joints at conveyor belts with textile plies.
17. Standard PN-74/C-94143. Textile/rubber belts for general purpose conveyors.
18. Standard PN-75/C-05011. Testing methods for conveyor belts. Determination of tensile strength as well as of relative and permanent elongation.
19. Standard PN-C-94147. Rubber products. Conveyor belt joints made using the vulcanisation method.
20. Standard PN-EN ISO 1120:2004. Conveyor belts. Determination of strength of mechanical joint. The static method.
21. Standard PN-EN ISO 7622-2:2002 (U). Conveyor belts with steel cords. Testing traction properties. Part 2: Measuring tensile strength.
22. Report from Research Project 620004/1. Testing endurance and extendability of textile/rubber belt joints. Not published. Wrocław 2004.
23. Żur T. Belt conveyors in mining. Poland: Śląsk Publishers, Katowice 1979.

Dr Dariusz MAZURKIEWICZ, Eng.

Lublin University of Technology
Nadbystrzycka 36, 20-618 Lublin, Poland
Tel./fax: +48-81-5384-229
e-mail: d.mazurkiewicz@pollub.pl
