Article citation info:
KOMANDER H, HARDYGÓRA M, BAJDA M, KOMANDER G, LEWANDOWICZ P. Assessment methods of conveyor belts impact resistance to the dynamic action of a concentrated load. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014; 16 (4): 579–584.

Henryk KOMANDER
Monika HARDYGÓRA
Mirosław BAJDA
Grzegorz KOMANDER
Paweł LEWANDOWICZ

ASSESSMENT METHODS OF CONVEYOR BELTS IMPACT RESISTANCE TO THE DYNAMIC ACTION OF A CONCENTRATED LOAD

METODY OCENY ODPORNOŚCI TAŚM PRZENOŚNIKOWYCH NA USZKODZENIA POWODOWANEDYNAMICZNYM DZIAŁANIEM MAS SKUPIONYCH*

The methods of testing the conveyor belt's puncture resistance in terms of assessing their suitability for the transport of sharp-edged rocks are presented. Methods of determining the critical impact energy of strokes are discussed together with a new method for determining the critical energy and the method of determining the average impact energy taking into account selected range of belt damages, which more reliably characterize their impact resistance. The algorithm and the method of estimating the critical impact energy based on measurements of energy absorbed by belt during rock mass strike is presented.

Keywords: *belt conveyor, puncture resistance, experiments.*

Przedstawiono metody badania odporności taśm przenośnikowych na przebijanie w aspekcie oceny przydatności taśm do transportu ostrokrawędzistych materiałów skalnych. Omówiono stosowane metody wyznaczania krytycznej energii uderzenia, przedstawiono nową metodę wyznaczania energii krytycznej oraz metodę wyznaczania energii średniej uderzenia obejmującą pewien zakres uszkodzeń taśmy, co bardziej miarodajnie charakteryzuje odporność taśmy na uderzenia. Przedstawiono algorytm oraz metodę szacowania krytycznej energii uderzenia na podstawie pomiaru energii traconej w trakcje uderzenia masy w taśmę przenośnikową.

Słowa kluczowe: *taśma przenośnikowa, odporność na przebijanie, badania laboratoryjne.*

1. Introduction

Long term experience of using belts on conveyors hauling the rock muck, as well as on short conveyors, used for example in bucket-wheel and bucket-chain excavators and in spreaders indicate that the main reason of the belts wearing are the damages in the form punctures and cuts caused by the impact of falling rock lumps at the conveyor loading section. Test carried out in the Belt Transport Laboratory (BTL) of Institute of Mining Engineering at Wroclaw University of Technology showed that at the beginning the belt damages are not visible on their external surface. Only after uncovering the belt core it is possible to find the presence of cord or textile core damages, detachments and fractures. During the conveyor belts operation the number of damages increase systematically, resulting in their cumulation causing the formation of broad cracks, tearing out of cover plates and the decrease of belt resistance. The belts operating on conveyors transporting the sharp-edges rock blocks, are worn almost only as a result of the above mentioned damages, which shorten their life-time. In order to prevent this, the methods of belt condition monitoring are developed. They allow to record, among other things, the magnitude, number and location of belt damages [7].

Another important factor increasing the operational life-time of the belt is its high puncture and cut resistance. Value of this resistance is a very important criterion of the belt operational life-time, since it protects the belt carcass against the water penetration and corrosion of steel cords or textile ply fracturing. Laboratory test on belt conveyors puncture resistance have been carried out for many years, both by domestic and foreign research centers and by some belts manufacturers [2, 3, 4, 5, 8, 10]. The scope of the tests is however limited to determining the critical energy of the impact. Basically, the effect of impact energy on the damage magnitude is not investigated. Method of testing the belt puncture resistance consists in striking the belt with head having the specified weight and falling from specified height (Fig. 1) and then in identifying the belt damages.

The measure of belt puncture resistance is the stroke energy:

$$E=m \cdot g \cdot h \text{ [J]} \tag{1}$$

where: m – head weight [kg], g – gravity acceleration [m/s^2], h – height of head fall [m].

Energy at which the first belt damages appear is generally accepted as critical energy E_k. The value of critical energy depends, among other things, on the head shape, method of belt support, strength of belt tension, head weight and height of its fall.

During the previous practice, the critical energy E_k has been the only criterion of belt puncture resistance assessment. Meanwhile, basing on tests carried out in BTL at Wroclaw University of Technology,

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

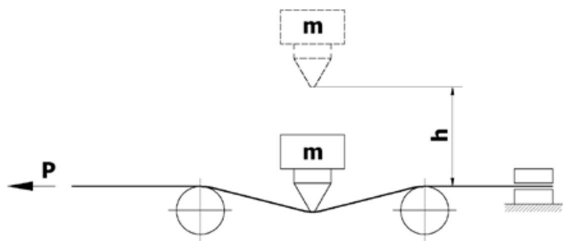

Fig. 1. Diagram of loading the belt with falling head.

it was stated that determining only the critical energy is insufficient for complete evaluation of the belt puncture resistance. It results from the fact that at striking with the energy higher than critical one, the size of damages, may be by far different for the different belts, in spite of the similar E_k value. Therefore the new testing method was developed, which allows to determine E_m – the average stroke energy for the specific range of damages size [6]. Moreover basing on tests, the new method of determining the critical energy E_k was proposed. The previous method consists in identifying the value of stroke energy which causes the first damages of belt. Determining the size of this energy is onerous and not very precise because of difficulties in assessing if the damage is the first (the smallest) one. With new method the critical energy is determined using the chart presenting the relation between the damage size *L* and the stroke energy *E* and it is defined as a value above which the damages of belt appear. E_k magnitude is here univocally determined by the point of chart $E=f(L)$ cross-cut with *E* axis.

Univocal method of the stroke critical energy determination is of special importance while selecting the belt for the operation conditions, because due to falling the heavy lumps of handled material, from big height, on the belt, the latter is selected taking into consideration its puncture resistance. The attempts of preliminary assessment of the critical energy value are taken, for example at the assumption, that the energy is proportional to the belt tensile strength [1]. The results obtained using this method are only the rough approximation and cannot replace the experimental determination of this value. Newly developed methods of determining the belts puncture resistance offer the possibility of much more accurate evaluation of this feature of the belt, what should result in the increase of their operational life-time under the heavy duty conditions. Competent assessment of the belt puncture resistance is also essential due to the fact that more and more belt users, require from the manufacturers to deliver the belts which comply the specified requirements concerning this feature.

2. Testing stand

Stand for testing the puncture resistance of belts should provide the belt load conditions as much as possible nearing the ones occurring at feeding stations. Such stand was constructed in BT Laboratory at Wroclaw University of Technology. The conveyor belt is fixed in the hydraulic clamps allowing for its tension equal 10% of its nominal resistance [6]. Under the belt there is a support with beam spacing of 200 mm which corresponds with the distance between idler roller stations at feeding sites in the majority of belt conveyors. Supporting element is placed along the axis of ram. Weight of head with carriage can be from 50 to 70 kg, while the throw height up to 3.0 m. There is a possibility of placing on the stand the sample up to 500 mm wide and up to 1300 long. Since the test of one sample requires more over ten throws of head from different heights, the sample is moved into new position after each stroke of head. Basic elements of the testing stand are presented on Fig. 2.

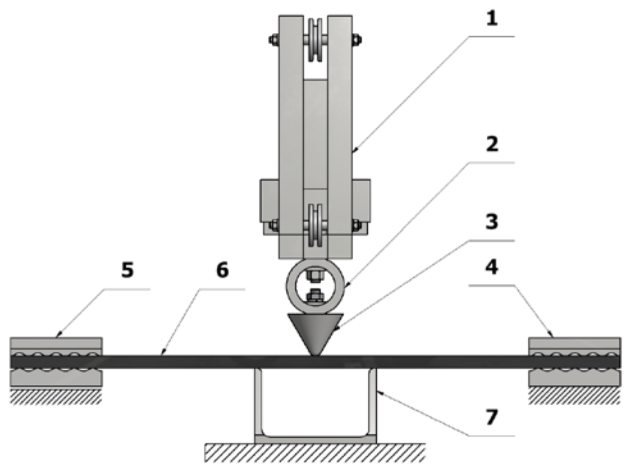

Fig. 2. Belt support and tension elements on testing stand; 1 - throw-off carriage, 2 - dynamometer, 3 - cone head, 4 - fixed hydraulic clamp, 5 - mobile hydraulic clamp, 6 - conveyor belt, 7 - support

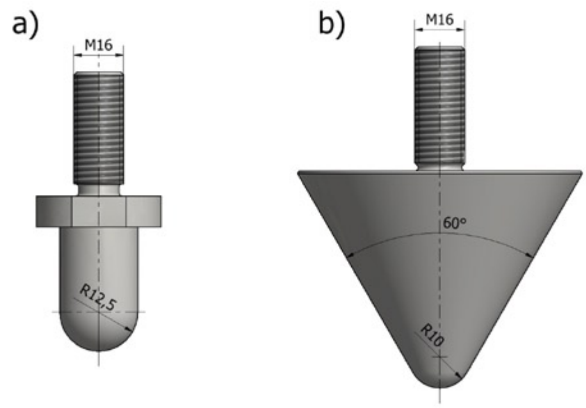

Fig. 3. Shapes and sizes of rams: a) spherical, b) cone

Testing stand has a measuring system to record the course of head stoke on the conveyor belt, the system for measuring the force of sample tension and ranging for measuring the height of head fall. The entire measuring system uses the software which allows to register and analyze the signals of stroke force, sample tension, stroke energy and relative value of energy absorbed when the head strikes the belt. On Fig. 3 two rams: spherical and cone, most often used during the tests, are presented.

3. Assessment of belt puncture strength through E_k critical energy assigning

Identification of critical energy [3, 4, 5, 6, 9] can be achieved basing on:

- visual evaluation,
- course of strike force,
- measurement of absorbed energy,
- damage magnitude vs. stroke energy chart.

Visual method of determining the E_k critical energy consists in striking the belt with increasing energy, then its rubber cover plate is detached in order to check under which stroke energy the first visible damage of belt cover plate or core, occurred. This method requires repeating the test on the second sample, because the result received while testing the first sample gives the rough E_k value. Test of the second sample is carried out by throwing the head from the height at which the first damage of belt was stated.

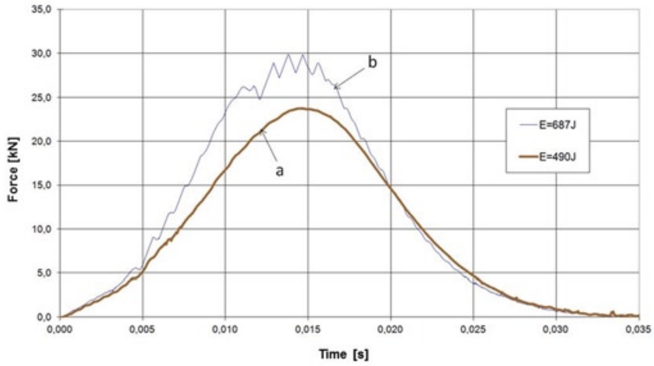

Fig. 4. Charts of stroke force vs. time for ST4500 12T+8T belt for different E stroke energies

Method of E_k determination basing on the stroke force chart consists in recording the course of the magnitude of head force stroke on the belt for specified number of strokes, and basing on comparing the shape of resulting charts on identifying the presence or absence of belt damage.

In the case of damage absence, the record of stroke force course is smooth and symmetrical, however when the damage occurs the chart has a form of polyline and is asymmetrical. On figure 4 the example charts of stroke force for the ST4500 belt with steel cords, are presented. The course of „a" chart speaks about the damage absence, while „b" chart speaks about the occurrence of damage. This method proves to be correct in the case of textile belts and belts with steel cords reinforced by textile flittings. It falls short, however, when the belts with steel cord and without reinforcement, are tested. At lower stroke energy values the cover rubber may be not damaged, however, the cord detachment from rubber can happen, what is not visible on the strike force course chart.

Method of E_k determination basing on measurement of absorbed energy utilize the assumption that the permanent damage of the tape should absorb the certain amount of energy [8]. Absorbed energy – E_t is a sum of E_c – energy exchanged into heat and E_{usz} – energy used for the damage formation.

$$E_t = E_c + E_{usz} \tag{2}$$

E impact energy is a sum of E_{odb} reflection (bounce) energy and E_t absorbed energy.

$$E = E_{odb} + E_t \tag{3}$$

E value is known, while E_{odb} value can be calculated knowing the speed of bounce and head weight. The speed can be measured or calculated from the power vs. time recorded during stroke chart. Integrating the chart of stroke power vs. time, the power impulse being a momentum change is obtained:

$$\int Pdt = m \cdot \Delta v \tag{4}$$

where: m – weight; v – speed.

If this value is divided by the weight, the speed change is obtained:

$$\Delta v = \frac{\int Pdt}{m} \tag{5}$$

Subtracting from this the value of head v_{ud} speed at the moment of stroke, measured or calculated from comparing the kinetic and potential energy of falling object, v_{odb} reflection speed is obtained:

$$v_{odb} = \Delta v - v_{ud} \tag{6}$$

i.e.:

$$v_{odb} = \frac{\int Pdt}{m} - \sqrt{2 \cdot g \cdot h} \tag{7}$$

On the basis of this E_{odb} reflection energy can be calculated:

$$E_{odb} = \frac{m \cdot v_{odb}^2}{2} \tag{8}$$

Knowing *E* impact energy and reflection energy the relative value of absorbed energy can be calculated:

$$E_t = \frac{E - E_{odb}}{E} \cdot 100, \% \tag{9}$$

Relative value of energy absorbed during the puncture is different for each belt. In order to use the described method in practice, one should, basing on the tests, determine the dependency between absorbed energy and stroke energy of head (E_t = f(E)) for the belt being tested. The curve is specifically bent after passing E_k critical energy of the head fall and is related with the absorption of the part of energy and exchanging it into belt damage work. (Fig. 5).

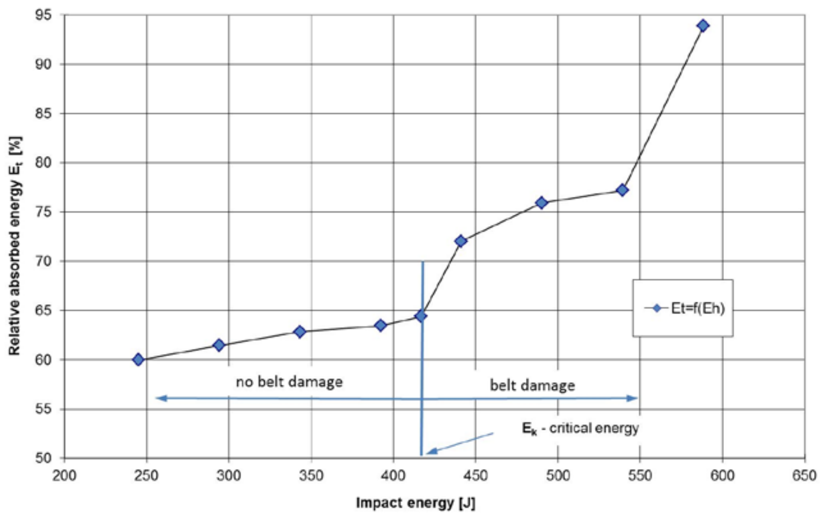

Fig. 5. Absorbed energy vs. Et=f(E) head impact energy for ST 3150 21+7-L belt with steel cords (spherical head)

This method proves to be correct while using the spherical head with R diameter of 12.5mm. The charts of absorbed energy in the case of cone head have different run (Fig. 6) and it is difficult, using them, to define the point of the increase of energy absorbed during the belt damage. This depends on the shape of cone head, which during penetrating the belt, increase its contact surface, reducing, at the same time, the unit pressure.

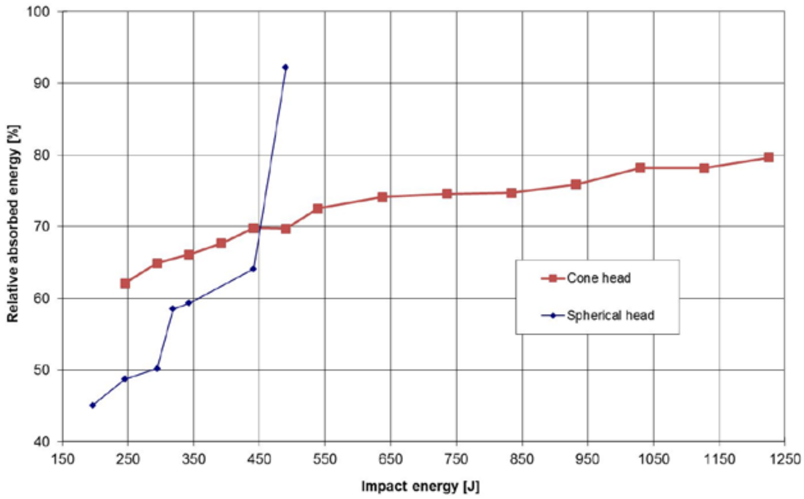

Fig. 6. Values of absorbed energy for spherical and cone head - ST 3150 H 14+7 belt

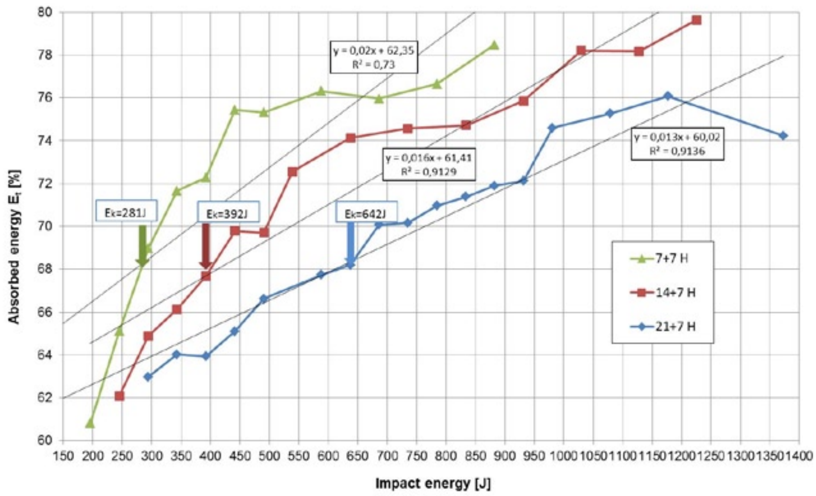

Fig.7. Example of critical impact energy determination by means of charts of absorbed energy (cone head) for three ST 3150 belts having different carrying cover plate thickness

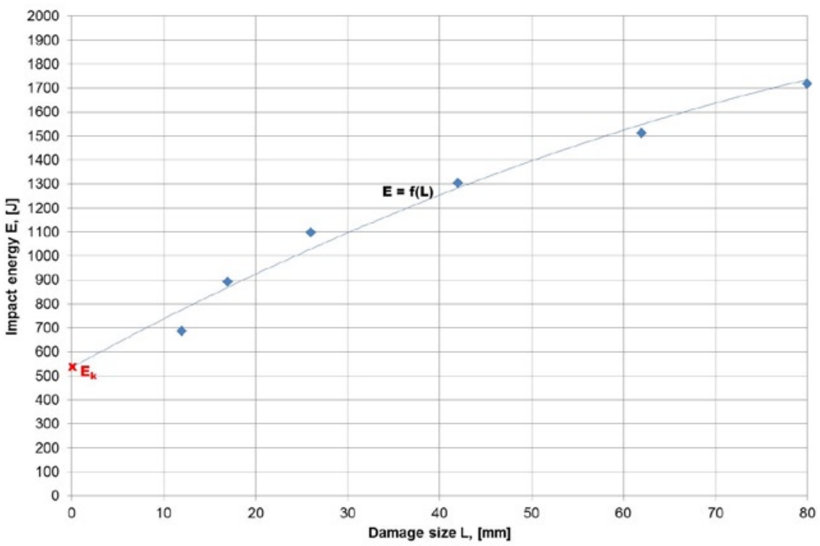

Fig. 8. Example of Ek determination using E=f(L) chart

Premising, however, that the belt damage must be related with absorbing the substantial amount of energy, the average value of absorbed energy in the form of trend line was determined. Compiling it with the curve of absorbed energy, the characteristic cross-cut of this chart with trend line was noticed, what means "absorbing" the bigger amount of energy than during the elastic bounce of the head. Analysis of sample after taking off the carrying cover plate showed that first belt damages originated from the impact energy, at which the curve of absorbed energy cut the trend line. Thus the point of cross-cut of absorbed energy chart with trend line is a critical point above which the belt is regarded as damaged. The impact energy corresponding to this point is thus the E_k critical energy. On Fig. 7 three charts of absorber energy with their trend lines are presented. The arrows show the values of E_k critical energy.

Method of E_k determination using damage size vs. impact energy chart consists in striking the belt repeatedly with increasing energy and then taking off the belt cover plate and identifying the damages. The belt damages have usually the shape of longitudinal cracks of cover plates of belt core. In belts with steel cords it may also be the delamination of rubber and cord. The measure of the damage size is the length (L) of crack or delamination. After that L[mm] damage size vs. E[J] impact energy charts are plotted. The charts are described by mathematical equations selected to have R^2 the correlation coefficient close to one (1). As a rule the high correlation coefficient is obtained describing the test results by line or quadratic equation. Cross-cut of E=f(L) chart with E axis points out the value of the E_k impact critical (Fig. 8) what means that it is described numerally by the absolute term of the equation. This method of E_k determination has the advantage i.e. its value is univocally identified by the cross-cut point of the chart and E axis. The E_k energy determined this way is defined as a value above which the belt damages occur. In the previous methods as E_k is taken the value at which the first belt damage was stated, what is usually stuck with a certain error.

4. Assessment of belt puncture resistance using the method of calculating average E_m energy of impact.

Basing on many tests of belts resistance, which were carried out in BT Laboratory at Wroclaw University of Technology it was stated that determining only the critical impact energy E_k is not sufficient for the correct evaluation of the belt puncture resistance. Checking the damage size vs. impact energy charts for different belts, it was stated that their course can have substantially different slope angle relative to L [mm], at simultaneous small difference of E_k critical energy. It can be seen on the example of two ST belt tests results presented on figure 9 [6]. E_k critical impact energy of both belts is almost identical. During strokes with energy higher than the critical one, significantly different damage sizes were obtained. For example at the impact energy of 900 J the damage of first belt is L=28 mm, while the second one is L= 75 mm. These results show evidently that they are not the belts with the same puncture resistance.

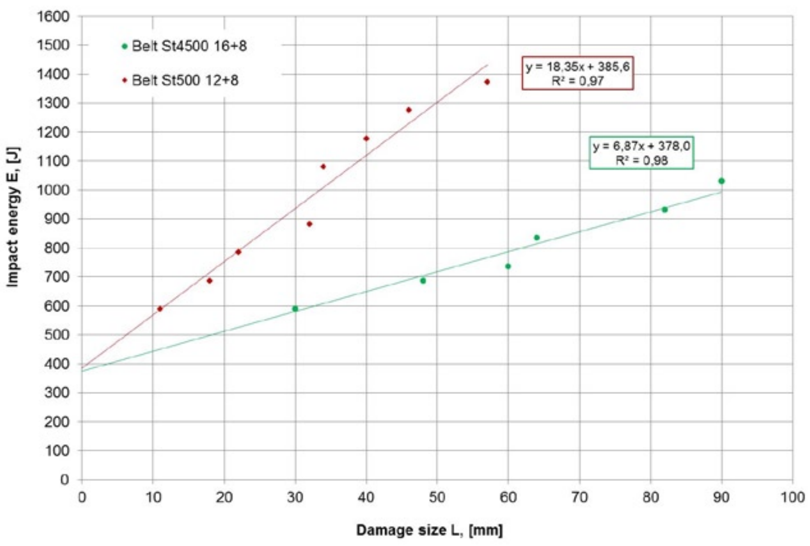

Fig. 9. Results of puncture resistance tests of ST 4500 16+8 and ST 5000 12+8 belts

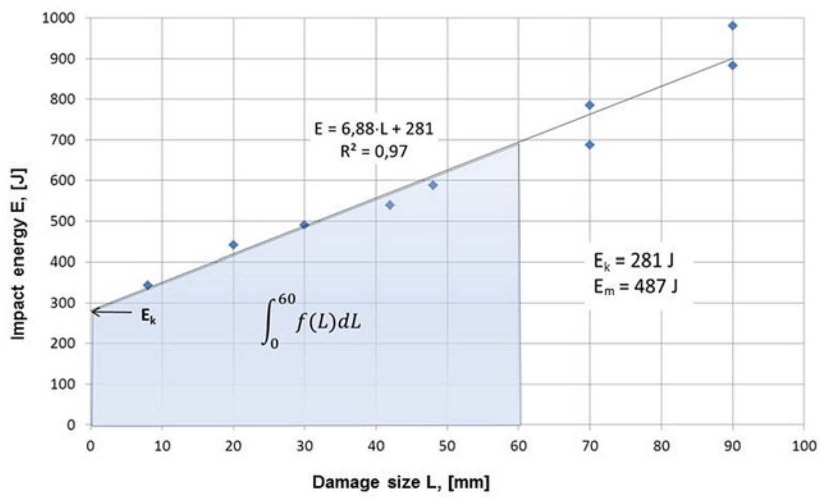

Fig. 10. Example of determining the puncture resistance of ST 3150 14+7 belt using E=f(L)dL chart (R10/60 cone head)

In order to assess, during the tests, the belts damage resistance, also at impact energies higher than the E_k critical energy, it was suggested to determine the puncture resistance basing on puncture chart from zero value up to equal, for all belts, value of L damage and calculate the average impact energy from the equation:

$$E_m = \frac{\int_0^L f(L) \cdot dL}{L}, [J] \qquad (10)$$

In tests carried out in BTT a common practice was to determine E_m for the range of L damage size from 0 to 60 mm. This range of damages corresponds to the most frequent belt damages encountered in the operational practice.

The example of determining the puncture resistance of ST 3150 14+7 belt is presented on figure 10. The measuring point are described by equation E = 6,88·L+281. For L = 0 mm, E_k = 281 J while the average energy calculated from dependence (10) for L ranging from 0 to 60 mm is E_m = 487 J. The puncture resistance of belt is characterized by two coefficients: E_k and E_m.

5. Summary

1) The puncture resistance of belts is of great importance with regard to their operational life-time, especially in haulage of rock mass. Methods of testing their properties, used in different research centers, due to the absence of relevant standards, are not similar, and thus the test results are not always comparable. It makes difficult, for example, the univocal evaluation of the efficiency of belt cross-reinforcements, aimed to improve their damage resistance.

2) The method of belt puncture resistance evaluation based on determination of E_k critical energy of impact can be of low reliability. It was found that in some cases, the belts having almost the same value of critical energy, substantially differ in size of damages being a result of the impact with energy bigger than the critical one. In order to evaluate the belt puncture resistance more reliably, the method of calculating E_m average energy, which includes the certain range of belt damages. It is justified to evaluate the belt puncture resistance basing on both E_k critical energy and E_m average energy.

3) The developed method of E_k critical energy determination using the damage size vs. impact energy chart, defined as a value above which the belt is damaged, allows for more accurate calculation of this value than in case of method in which critical energy is defined basing on the first stated damage.

4) Method of E_k critical energy determination by means of analysis of impact force course, does not give the reliable results and can only have a supportive function during the test.

5) New, presented here, method of determining the belt puncture resistance by measuring the absorbed energy is an attempt of simplifying the test to eliminate the rubber cover plate and belt core delamination in order to check if the damage occurred. The results obtained so far are promising with regard to establishing the critical energy of impact. It seems to be advisable to carry out further tests on using this method also to evaluate the belt resistance for the impacts having the energy higher than critical.

Acknowledgement:
The research work financed with the means of the State Committee for Scientific Research (Poland) in the years 2010-2013 as a research project.

References

1. Antoniak J. Przenośniki taśmowe w górnictwie podziemnym i odkrywkowym energooszczędne. Wydawnictwo Politechniki Śląskiej, Gliwice 2010: 176-178.
2. Elvers K, Schnell W, Tonn H. A universal, highly effective cross reinforcement system for conveyor belts. Bulk Solid Handling 1989; 4: 393-396.
3. Flebbe H, Hardygóra M. Zur Beaufschlagungsfestigkeit von Fordergurten. Braunkohle 1986; 7: 196-199.
4. Flebbe H. Untersuchung von Fordergurten auf ihre dynamische Festigkeit. Braunkohle 1982; 6: 186-191.
5. Hardygóra M, Komander H, Bajda M, Komander G. Conveyor belt with increased operational wear resistance. Transport&Logistics 2010; 19: 26-32.
6. Hardygóra M, Komander H, Bajda M, Komander G, Lewandowicz P. Taśma przenośnikowa o zwiększonej odporności na uszkodzenia eksploatacyjne przeznaczona do stosowania zwłaszcza w przemyśle wydobywczym węgla, rud miedzi i surowców skalnych. Sprawozdanie z badań Nr LTT/21/13 z realizacji projektu rozwojowego NCBiR Warszawa Nr 09-0009-10/2010, Wrocław 2013.
7. Kwaśniewski J. The use of monitoring to improve the reliability and endurance of continuous coal handling systems. Archives of Mining Science 2011; vol. 56; 4: 651-664.
8. Lewandowicz P, Prykowski J. Badania odporności taśm przenośnikowych na przebicia. Górnictwo Odkrywkowe 1996; 6: 39-52.
9. Palczak Cz, Komander H. Taśmy przenośnikowe do transportu materiałów skalnych. Cement Wapno, Gips 1971; 9: 288-292.
10. Sohnemann R, Heynhold J, Rickert K. Ermittlung das Beaufschlagungs – und Schlitzwiderstandes von querarmiertem Stahlseilgurten. Glückauf – Forschungeshefte 1980; 41(5): 211-213.

Henryk KOMANDER
Monika HARDYGÓRA*
Mirosław BAJDA
Grzegorz KOMANDER
Institute of Mining Engineering
Wroclaw University of Technology
Machinery Systems Division
Plac Teatralny, 50-051 Wroclaw, Poland

*KGHM Cuprum R&D Center, Poland
ul. Gen. W. Sikorskiego 2-8, 53-659 Wroclaw

Paweł LEWANDOWICZ
Poltegor-Institute, Institute of Open Cast Mining
ul. Parkowa 25, 51-616 Wrocław

E-mails: henryk.komander@pwr.wroc.pl, mhardygora@cuprum.wroc.pl,
miroslaw.bajda@pwr.wroc.pl, grzegorz.komander@pwr.wroc.pl
pawel@igo.wroc.pl