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Experimental research of a new generation of support systems for the transport of mineral raw materials

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Within the transportation of materials in mining using the belt conveyor systems, a conveyor belt is particularly the component with the highest wear rate. The development trends in the field of conveyor belt wear, in terms of disruption damage, are mostly focused on the innovation of damping components of buffer beds with impact rubber bars. Impact bars are an essential component of innovative buffer beds suitable for several types of belt conveyors. In mining, these bars are also used in buffer beds of bucket wheel excavator used for the extraction of overlying soils.

The most important attribute of this support system is the impact resistance. Therefore, the output of the present paper is the determination of the limit impact dynamic loading based on the quantification of the force effect. The buffer bed eliminates the shortcomings of classic constructions, above all a point contact, and it allows better sealing-off of the whole place of an impact if required. Construction of the buffer bed should provide sufficient stiffness, flexibility, ability to direct conveyor belts at the direction of conveying, absorb the kinetic energy of the transported material, and ensure a surface contact between the material and the conveyor belt by increasing the surface friction drag. This paper deals with the experimental measurement of three kinds of impact rubber bars with different frameworks. Impact characteristics of the bars are significantly affected by the material and the type of metallic framework. The examined impact bars were exposed to the effects of the dynamic impact loading that is of great importance and facilitates the simulation of the belt conveyor system operation. The entire loading process was documented and impact load curves in time were analysed. The depth of penetration and the values of impact load were determined.

Key words: *impact loading, impact bars, resistance*

Introduction

The wheel excavator (Fig. 1) usually operates on a continuous basis, and it is an important large-scale machine designed for surface mining of large volumes of soil and minerals, mainly overburden, lignite and hard coal (Bošnjak et al., 2013; Gondek, 2013; Zhi-wei et al., 2010). Conveyor belts are an important part of the wheel excavator, and they are basic structural component of many conveying and handling equipment in different industries. The long-time problem of users not only in Europe but also in the world is the solution of their maximal use with respect to their lifetime and ecological acceptability.

Material flow within the operation of technological equipment results in abrasive, erosive, or fatigue wear of their functional surfaces and structural components that requires stoppage and repairs with undesired economic consequences for operators (Voštová, 2010). Currently, a compression of rollers with rigid bearing and garlands at the place of impact are used. By using of these systems, frequent punctures because of point (line) contact belt – roller, crippling of the belt from the direction of transport due to the effect of the uneven impact of transported material and last but not least to the destruction of the rigid construction of belt conveyor route occur. The new solution is created by impact bars. The principle of this device is based on the fact that the material conveyed to the point of impact of the conveyor belt with rollers falls on the impact bars that provide control of the fall energy, as well as the elimination of the crushing and reducing dust. It also significantly reduces damage to the conveyor belt, especially in terms of its punctures (Hapla et al., 2013). Impact bars are attached to the frame using the screw connection. They are installed at the place of a top branch of the conveyor belt route. It is the space between two top brackets with rollers at the place where the transported material impacts the conveyor belt (Gondek et al., 2014).

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Fig. 1. Wheel excavator.

Rock hat falls onto the conveyor belt is monitored from the moment of contact with the belt and it can be divided into four phases (Gondek et al., 2014; Mozer et al., 2015; Ondráček, 1990). The first phase occurs at the moment of contact of the block of rock with a belt and ends at the moment of impact the belt (with rock) on impact bars. In the second phase, the belt is in contact with the impact bars and subsequently is reflected from them and moved upward. By separating the block of rock lying on the belt from impact bars, the third phase of the movement comes. In the fourth phase, the separation of rock block from the belt occurs and follows his free movement, until once again falls on the belt and the whole process is repeated.

To verify the model of buffer bed dynamics for performing computer simulations of the impact of the block of rock on the conveyor belt, it is necessary to experimentally determine the impact resistance of an essential component of innovative buffer beds, what is work aims.

Materials and Methods

The research question is the effect of impact bars of innovative buffer bed on the conveyor belt which results in its prolonged life. Conveyor belts are basic and universal means of transport of particulate materials. The structure thereof can vary, and it usually consists of conveyors connected together with so-called transfer chutes where the transported material is directed from the feed conveyor onto the receiving one. These are critical places, a source of dust and rapid energy transformation, and require special attention from the designer because a poorly designed chute may be the cause of costly failures and downtime (Czuba, 2013). Belts are often damaged when heavy objects land on the belts. Due to the impact of landing material, conveyor belts are subject to extreme strain. The perforation of the belt caused by the landing material is the most common failure. The most strained place is the site of the direct contact of the landing material and conveyor belt absorbing the related energy (Honus et al., 2017).

Many works studied the optimisation and analysis of belt conveyors from different perspectives. Roberts (2003) presented the criteria for the selection of the most appropriate chute geometry to minimise chute wear and belt wear at the feed point. Benjamin et al. (2010) analysed transfer chutes with practical examples. Maneski et al. (2012) concentrated on the life of belt conveyors in connection with the life-span of supporting steel constructions taking into consideration their loaded vibrations. Honus et al. (2017) measured the size of deformation energy produced by the impactor falling onto the conveyor belt and cushion carrying idlers. The place of impact as the critical site of the whole facility is subjected to extreme stress.

During the conveyor belts operation, the number of damages increases 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 in conveyors transporting sharp-edge rock blocks are worn almost exclusively as a result of the damage mentioned above which shortens their lifetime. Long-term experience of using belts on conveyors used for example in bucket wheel and bucket-chain excavators and in spreaders indicate that the main reason for the belt wear is the damage in the form of punctures and cuts caused by the impact of falling rock lumps at the conveyor loading section (Komander et al., 2014).

Scheme of the investigated system is depicted in Fig. 2. The whole process of the rock impact on the belt can be divided into three areas.

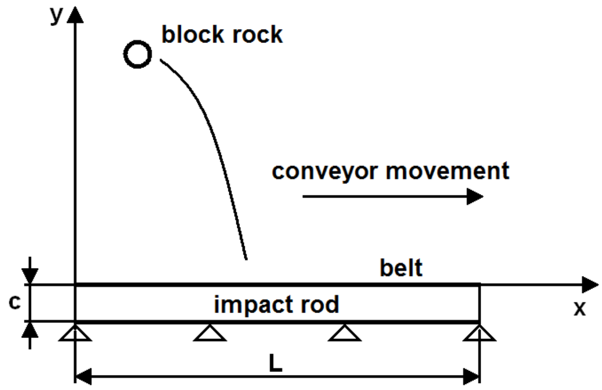


Fig. 2. Scheme of the investigated system (Gondek, 2014).

In the first area, the rock moves as a free body. The second area starts when the block touches the belt and ends at the moment of its impact (together with the belt) on the impact rods. Consequently, the rock block goes back through the second area to the first one and alternatively the process may repeat. The first, second and third areas are specified by the vertical coordinate (Gondek, 2014). At the perpendicular impact of the transported piece material, large impact loads are acting upon the conveyor belt and cause its puncture. The material physically contacts the conveyor belt for as short as 0.03 to 0.12 s (Marasová, 2001). During such period, the conveyor belt is affected by the force that is several times larger than the material weight. As the conveyor belt moves, the material receives, following the physical contact with the belt, a strong horizontal impulse. The impact energy is absorbed by the deformation work of the conveyor belt and impact idlers. Therefore, the conveyor belt gets worn out due to abrasion. If the conveyor belt and idler system are not able to absorb the impact energy of the falling material, the puncture occurs (Taraba et al., 2017).

High puncture and cut resistance of the belt are important factors increasing its operational lifetime. The very important criterion of the belt operational lifetime is the value of this resistance since it protects the belt carcass against the water penetration and corrosion of steel cords or textile ply fracturing. Laboratory test on conveyor belts puncture resistance have been carried out for many years by both, domestic and foreign research centres, and by some belts manufacturers. Methods of testing their properties, used in different research centres, due to the absence of relevant standards, are not similar, and thus the test results are not always comparable (Komander et al., 2014). The methods of testing the conveyor belt’s puncture resistance are presented in (Komander et al., 2014; Andrejiová et al., 2016).

Method of testing the belt puncture resistance consists in striking the belt with a head having the specified weight and falling from a specified height and then in identifying the belt damages. The value of critical energy depends on the head shape, method of belt support, strength of belt tension, head weight and height of its fall. The energy is proportional to the belt tensile strength (Antoniak, 2010).

Assessment of the damaging of a conveyor belt and damping components of impact stands can be carried out while applying several methods. In this work, an experimental method was used. The most frequently used methods of the evaluation of experiment results includes statistical methods (Andrejiová, 2011; Grinčová et al., 2015), simulation methods (Andrejiová et al., 2016; Husáková, 2010) and the methods of mathematical modelling (Taraba et al., 2014; Grinčová et al., 2016; Andrejiová, 2016).

The innovative buffer bed under the place of impact greatly reduces the negative influence of deformation energy in the conveyor belt. Impact bars as certain construction components of innovative buffer bed are subject of research in this work. Impact bar has the characteristics of high energy absorption, low friction, product spillage and scattering elimination. Impact bars are widely required in many transport products of mining, heavy machinery, power plants, cement plants, and some other. After the long-term shocking and stabbing of drops, the life of the bar and buffer bed will decline as deformation, wear and bonding layer tear (Kangmei et al., 2017). The bar can reduce the vibration of the parts, maintain high stiffness, extend equipment life, decrease the cost of metal and energy consumption, lessen noise, and improve working conditions for workers (Chen, 2010).

The impact bar is a metal rubber-plastic composite materials; its top part is wearing layer, follows rubber layer and the metallic framework (Fig. 3). Rubber layer is the middle layer of the bar, which mainly absorbs the most impact load and lessen vibration. The rubber layer can almost absorb the impact load of drops to reduce the impact on the conveyor belt and improve the force condition of blanking point. A plastic layer of the metal rubber plastic composites is usually compound of various plastic. Plastic components and relationship of each plastic layer thickness are related to the stiffness of plastic composite layer and effect of anti-friction and noise reduction (Kangmei et al., 2017).

There are 2 main types of impact bars of metallic framework: (i) aluminium alloy framework, which is commonly used in the last century in German, but the aluminium one can easily be displacement and deformation, which is not safe to use undermining; (ii) steel framework, which is durable, stable, easy fixed and widely used. The adhesive technology between steel skeleton and rubber needs to be improved by higher equipment and technique. As the development of conveyor industry supporting products, conveyor impact bars have to develop towards the direction of higher performance index: higher polymer, higher wear resistance, lower friction, better corrosion resistance, higher temperature resistance, higher elastic and advanced manufacturing process (Kangmei et al., 2017). The type of impact bar at the place of landing material significantly influences the size of deformation energy carried by the conveyor belt.

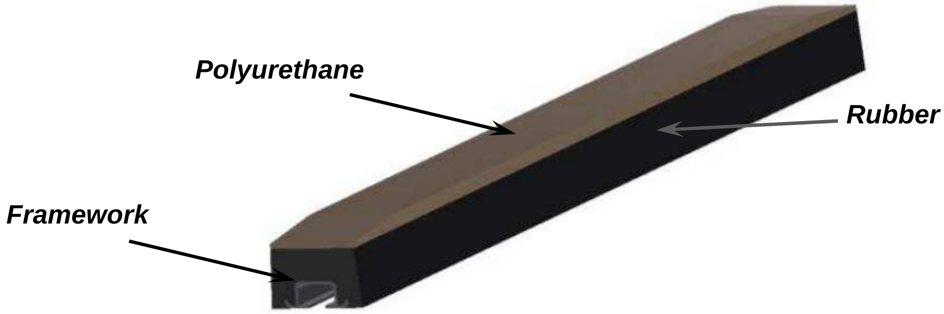


Fig. 3. Impact bar.

Experiments were carried out using three kinds of impact bars with sizes (length/width/height) 1,235/100/75 mm; two types of bars of steel framework (classic and strengthened respectively) and the one bar of aluminium framework. The impact bar (Boháč, 2010), i.e. a metal section with a vulcanised conducting polyurethane panel on top (Fig. 3), absorbs dynamic effects of the material falling onto the conveyor belt.

Experiments aimed at identification of the effects of the framework on the impact resistance were carried out using the testing equipment (Grinčová, 2006). The experiment methodology is based on the European and national legislative requirements regarding the transportation carried out using belt conveyors (Grendel et al., 2014; Grinčová et al., 2008). Using a pulley block, a drop hammer of the required weight is elevated to the chosen height, from which it is dropped freely onto the sample. Using a tensometric detector (Kučera, 2011), the impact load F_I is measured. During one measurement cycle lasting 10 s, 10,000 values are recorded for each of the parameter mentioned above. The measured values are then used to identify the time flow (Fig. 4) of the entire measurement.

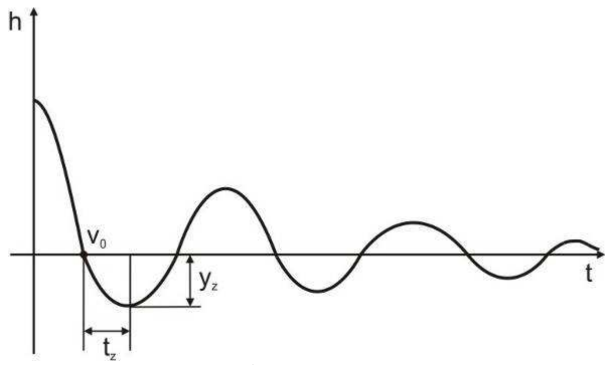


Fig. 4. Measurement time flow (v_0 – drop hammer speed just before the impact, y_z – maximum drop hammer's imprint depth in the testing sample, and t_z – measurement duration).

The measured values are then used to identify the time flow of the entire measurement. The weight of the drop hammer without additional calibrated weighs is 50 kg, and the measurements were carried out using the total weight of 105 kg. The drop height of the drop hammer was gradually increased from 2 m to 2.5 m with 0.5 m stepping. The testing of impact resistance of impact bars was carried out using the spherical impactor with the radius of 25 mm.

Result and Discussion

Conveyor belt service life is prolonged in practice while applying several methods. One of them is a deeper understanding of the belt properties and behaviour in complicated loading conditions. Understanding and improvement of physical, mechanical, and functional properties of individual materials that form a conveyor belt facilitate adjustment of the properties of the composite itself. Another method is to direct the attention on the innovation of structural components of a belt conveyor as such. The most critical place is the chute where the conveyor belt is damaged by the falling material. A key belt damage parameter is the value of the absorbed deformation energy. A certain portion of deformation energy is absorbed by the support system. Increasing the percentage of the energy absorbed by this system prolongs the service life of a conveyor belt. Replacing a conventional support system with innovated buffer beds significantly reduces the effect of the deformation energy on the belt. These impact beds are formed by impact rods, use of which brings several advantages. The present paper examines three various types of impact bars:

- bar of classic steel framework,
- bar of strengthened steel framework,
- bar of aluminium framework.

The examined bars were exposed to the effects of the dynamic impact load. A drop hammer weighing 105 kg with a spherical impactor was dropped from the heights of 2 and 2.5 m onto individual impact bars. The spherical impactor represents raw ore, free of sharp edges. The impact process is documented by the measurement development presented in Fig. 5. The measured data were used to create diagrams for the drop height and the impact load in relation to time, at the fall of the drop hammer with the weight of 105 kg from the height of 2.5 m onto the tested impact bars. The observed relations indicate that the impact process in case of both impact bars of steel framework is shorter, a drop hammer's bounces after the first impact have lower heights, and the impact load F_I is lower than in case of the bar of aluminium framework. The analysis of the examined drop heights showed that the bar with an aluminium framework has the maximum impact load and its damping ability is the lowest out of the examined bars. The most efficient damping was observed in the bar with a strengthened steel framework.

Data obtained from individual measurements were recorded in a .txt file. Each file, containing 30,000 values, was transformed and the measured data were subsequently visualised and evaluated. For each measurement, the values of the impact load, depth of penetration, and time characteristics of the impact process had to be identified. The impact load was determined as the maximum value out of the group of the measured forces. This value was also assigned a depth of penetration, depending on corresponding times. The measurements in the case of the bar of strengthened steel framework at the drop hammer impact from the height of 2 m were not recorded due to the operator's fault; these data are thus missing.

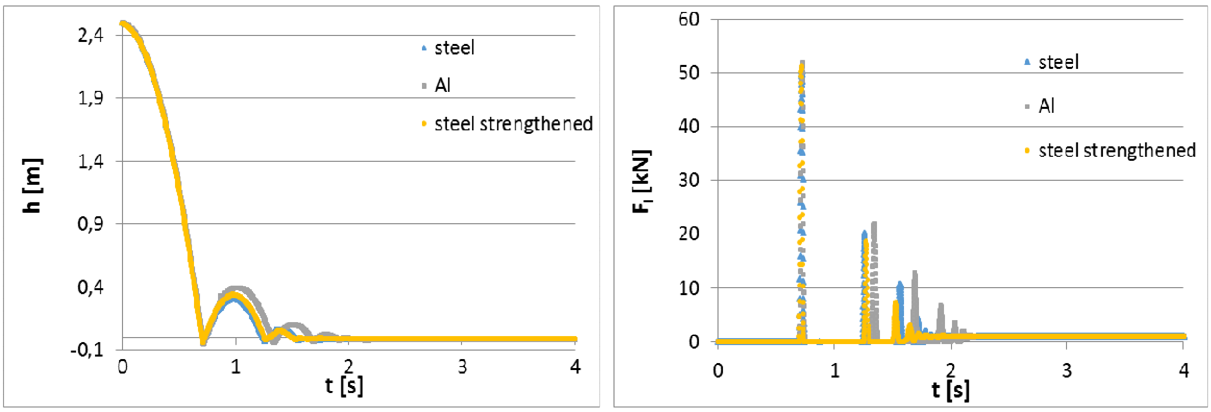


Fig. 5. Effects of the framework on the developments of the height h and the impact load F_I at the fall of a drop hammer with the weight of 105 kg from the height of 2.5 m onto the impact bar.

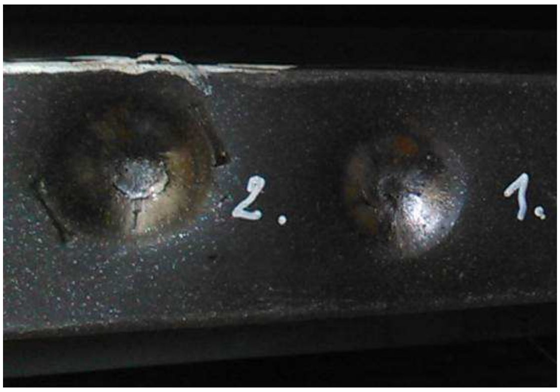
The measured results are shown in Table 1. Following individual measurements, impact bars were visually inspected. Degrees of the damage to individual bar parts were analysed. In the upper part of the bar, a permanent indent was observed, corresponding to the impactor shape. Bars also showed damage to the framework on the bottom side of the bar. Direct determination of bar deformation was not planned; therefore, the depth of penetration values were identified from the measured data. Fig. 6 shows the indents on impact bars after conducted experiments, whereas the observable depth of penetration is, unlike the measured value, reduced in the elastic deformation. On the basis of the obtained results, we can state that with a growing drop height

(2 - 2.5 m), at a given drop hammer weight (105 kg), there is an increase in the values of impact load and depth of penetration. The impact of the drop hammer onto the bar was monitored using a camera, while a halogen reflector illuminated the bar. Due to a short duration of the drop hammer impact onto the impact bar (approximately up to 750 ms), a high-speed camera had to be used. Using a high-speed camera TroubleShooter TSHRMM (resolution 1280x1024 pixels, frame rate 250 FPS) and the MiDAS Player software, images (Fig. 7) were obtained showing the impact of the drop hammer from the height of 2.5 m on the impact bars at the first impact.

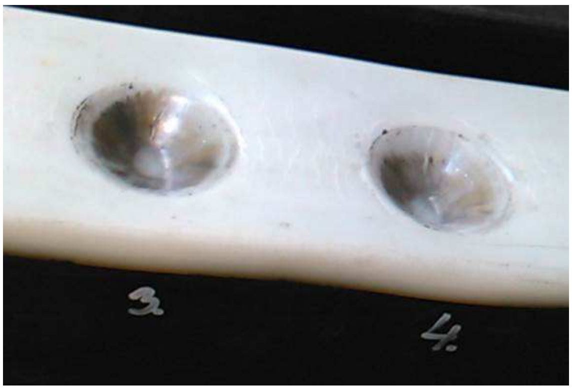
Tab. 1. Measured values (h – drop height, y_z – depth of penetration, and F_I – impact load).

Type of framework	**h** [m]	**y_z** [mm]	**Number of indents**	**F_I** [kN]
steel	2	36	1.	46.6
steel	2.5	40	2.	50.5
Al	2	44	3.	46.8
Al	2.5	48	4.	51.9
steel strengthened	2.5	35	5.	51.4

An edge of a bar with classic steel framework was visualised using a white marker. The field of view of the camera at given settings did not facilitate the documentation of the changes in height during the damping. However, the bar deformation degree is evident; a bar with aluminium framework shows greater surface deformation. A combination of input test parameters, i.e. the drop height, drop hammer weight and impactor resulted in the deformation of the impact polyurethane plate. Higher impact load and deeper penetration were observed for the bars of aluminium framework than for both bars of steel framework. From both impact bars of steel framework, deeper penetration was represented by a bar of classic steel framework. No damage to steel strengthened framework was observed.



a)

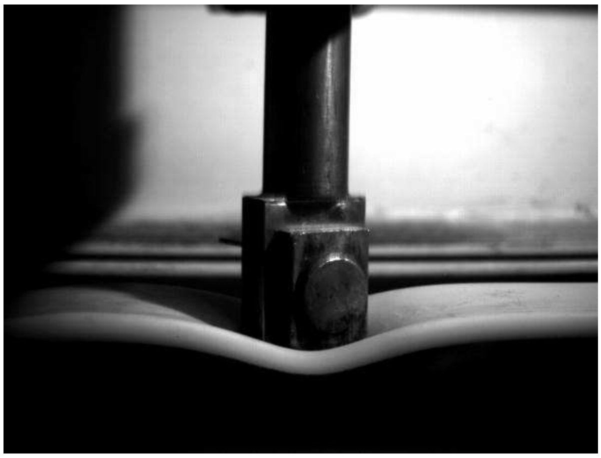


b)

c)

Fig. 6. Impact bars after experiments (number of indent according to Table 1), a) bar of the classic framework, b) bar of aluminium framework, c) bar of the strengthened framework.

The effect of the framework on the depth of penetration is shown in Fig. 8. Deeper penetration of aluminium framework was observed than for steel framework in each monitored drop height. Greater impact loads correspond to the fall of the drop hammer from a greater height, i.e. the height of 2.5 m.



a) *b)*

Fig. 7. Impact of drop hammer (height of 2.5 m) on impacts bars, a) bar of the classic framework, b) bar of aluminium framework.

The paper (Marasová et al., 2014) was focused on the monitoring of the effect of the strengthened steel framework on the impact resistance of impact bars. Experiments were carried out with a spherical impactor for the drop hammer weight of 90 kg and the drop heights of 1 – 2.5 m with 0.5 m increments.

The impact bar with a strengthened framework was affected by a greater impact load than in the case of the impact bar with a non-strengthened framework, whereas its value is growing with a growing drop height. The flexure on the impact bar with a classic framework is larger than on the impact bar with a strengthened framework, at the heights of 2 – 2.5 m, as much as 30 – 40 %.

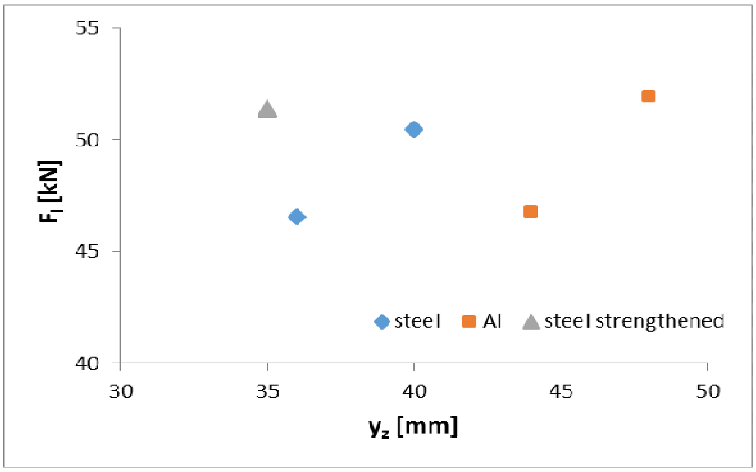


Fig. 8. Effect of the framework on the impact load F_I depending on the depth of penetration y_z.

Conclusion

Punctures in the operated conveyor belts cause great economic losses. At places where the rock impacts a conveyor belt, impact idlers are installed; they are intended to damp the impacts caused by the transported material, falling onto a conveyor belt. These idlers are exposed to the greatest load and are the most frequently damaged parts which must, therefore, be replaced. The solution thereof is the use of innovative buffer beds. Such structure, consisting of impact bars, ensures sufficient hardness, flexibility, and direction of a conveyor belt, absorbs the kinetic energy of the falling material and ensures an area contact between the material and the conveyor belt at the impact site while reducing the frictional resistance. The main damping material, which the bar is made of, is rubber. On the bar surface, there is a layer made of the material of high abrasion resistance (e.g. polyurethane, polyethene), intended to reduce the friction between the belt and the impact bar.

Experimental tests of the dynamic impact load are very important and facilitate faster solutions to problems regarding conveyor belt damage and rupture. Experimental measurements of progressive damping components by dynamic impact loading enable identification of their utility properties. Obtained results describe how innovative buffer beds can absorb the energy of falling material. This is very important for predicting the service life of conveyor belts, without its damaging during operation. The experiment results indicate that the impact bars with the steel framework have higher impact resistance than the bar of aluminium framework. Strengthening of steel framework even improves impact resistance. The affecting impact load causes a slight deformation of the impact bar with aluminium framework. Bar damage induced by the impact, however, will not affect a conveyor belt quality, i.e. defects of impact bars will not cause the conveyor belt damage. Basically, it is a solution of the problem regarding the reduction of the number of conveyor belt punctures occurring along the conveyor routes in large machines as well as in long-distance conveyor belt systems. As the main problem of the conveyor belt damage is the dynamics of the impact of the transported rock, the measured impact load exerted at the impact of the drop hammer on the impact bar examined its resistance to puncture.

The conclusions presented in the article may thus lead to belt conveyor construction optimisation and contribute thus to longer life of conveyor belts. At the same time, there is a great potential for further research, as the topic of longer conveyor belt life via changing the types of impact bars at the place of impact has not been widely investigated. These issues will be the subject of further research in this area.

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