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LABORATORY TESTS OF THE USE OF BELT CONVEYOR ELEMENTS FOR MOULDING SANDS

BADANIA LABORATORYJNE ZUŻYWANIA ELEMENTÓW PRZENOŚNIKÓW TAŚMOWYCH DO MAS FORMIERSKICH

Key words: wear, belt conveyor, electrode welding, structural steel, hardened steel, acid-resistant steel, polyethylene.

Abstract The article presents the results of research on the wear of belt conveyors' elements made of various materials. For the purpose of the experiment, a test stand was built, reflecting the real working conditions of the conveyor belt, on which abrasive tests of samples made of appropriately selected materials and a control sample of steel were carried out. Obtained wear values indicated the most wear-resistant material.

Słowa kluczowe: zużycie, przenośnik taśmowy, spawanie elektrodą, stal konstrukcyjna, stal hartowana, stal kwasoodporna.

Streszczenie W artykule zaprezentowano wyniki badań dotyczące zużywania się elementów podajnika taśmowego wykonanych z różnych materiałów. Na potrzeby eksperymentu zbudowano stanowisko badawcze, odzwierciedlające rzeczywiste warunki pracy taśmociągu, na którym przeprowadzono testy ścierne próbek wykonanych z odpowiednio dobranych materiałów oraz ze stali kontrolnej. Uzyskane wartości zużycia wskazały najbardziej odporny na zużywanie ścierne materiał.

INTRODUCTION

The wear of machine elements working in abrasive environments, such as soil cultivating machines, earthmoving machinery, or bulk material transport systems, is one of the basic technical problems that has been the subject of scientific research for decades. It is the cause of huge material losses and frequent machine downtime. Belt conveyors play a fundamental role in the transport of bulk materials. They are often used as components of dispensers and complex transport networks. In belt conveyors used in iron foundries for the transport of moulding sands, the belt edges are guided in special guard rails made of steel sheet, which prevent the material from spreading sideways. The basic problem faced by users of such belt conveyors is the rapid wear of the guard rails. These elements are quickly getting worn-out and several replacements are required during a single period of machine operation. The wear that occurs at the point of contact of the belt with the guard rail is abrasive. The damaged element is shown in **Figure 2**. The article presents the results of tests on the wear of several different materials (steel types), which are used together with the belts of the conveyors.

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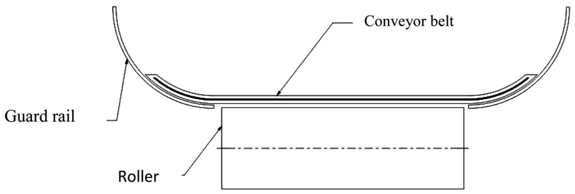

Fig. 1. Diagram of the conveyor cross-section [L. 1]
Rys. 1. Schemat przekroju przenośnika [**L. 1**]

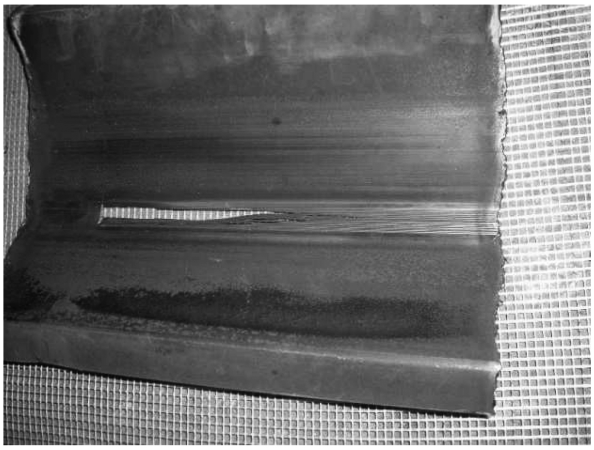

Fig. 2. Worn parts of the guard rail carrying the conveyor belt [L. 1]
Rys. 2. Zużyte elementy półkoryta prowadzącego taśmę przenośnika [**L. 1**]

From the data provided by the user of such a conveyor, it appears that the largest wear of the guard rails occurs in the vicinity of loading stations and places where moulding sand passes between the conveyor belt and the rail. These guard rails are usually made of weldable, ordinary quality structural steel, pressed from a metal sheet with a thickness of 2–3 millimetres. The guard rail segments are welded together with a butt weld with reinforcements. Therefore, the replacement of worn guard rail segments is very troublesome. The abrasion (perforation) of the rail can lead to tearing the conveyor belt and scattering the material in hard-to-reach places.

The purpose of the research was to determine the possibility of extending the lifetime of moulding sand conveyors by using an alternative material for the guard rails. Although, in practice, many materials are more resistant to abrasive wear than common low carbon steel, the economic effect of using more expensive material may be determined by its availability and the price relation of the better material and the effect of increasing the durability of the conveyor. The results of the research undertaken should provide an objective basis for such strictly economic calculations.

In the literature on the subject, many papers can be found regarding the methods of testing related to the wear of machine elements working in abrasive environment as well as the results of such tests. Commonly used standard test methods include the Haworth method, which was developed by ASTM. **Figure 3** shows the Haworth-ZIS 116 device used to test dry abrasion with loose abrasive [**L. 2**]. A flat sample of the material being tested is pressed here by adjustable force to a rubber rotating disc immersed in a bowl filled with loose abrasive. In this arrangement, the contact of the sample with the friction surface is linear and the unit pressure on the sample is not clearly defined. In addition, the frictional wear model used in this test does not exactly match the friction conditions between the plate and the rubber belt in the conveyor belt, when only single grains get into this space.

Another solution is the Taber-Abraser method [**L. 3**]. The test in this case consists in mounting the sample on the rotating plate, where it is rubbed by two symmetrically spaced abrasive wheels, which apply specific pressure on the plate [**L. 4**].

In [**L. 4, 5**], the authors presented a study on the wear of a cylindrical sample immersed in an abrasive-filled rotating vessel. Here, the sample of the material being tested is fixed at a certain distance from the axis of rotation of this vessel. A similar method is described by Napiórkowski [**L. 3**] under the name of the ‘rotating bowl’ method. The method of ‘soil bin’ is the reverse of this method. In the ‘soil bin’ method, the sample is placed on the rotating mechanism and moves, while the bowl does not rotate [**L. 4**]. All these methods do not accurately reflect the friction conditions between the guard rail and the conveyor belt during the transport of moulding sand.

For the purpose of this paper, in order to obtain more reliable and comparable test results, a test stand reflecting the friction conditions between the conveyor belt and the guard rail made of various materials was designed and built. This test stand can also be successfully used for all other tests of abrasion resistance of materials.

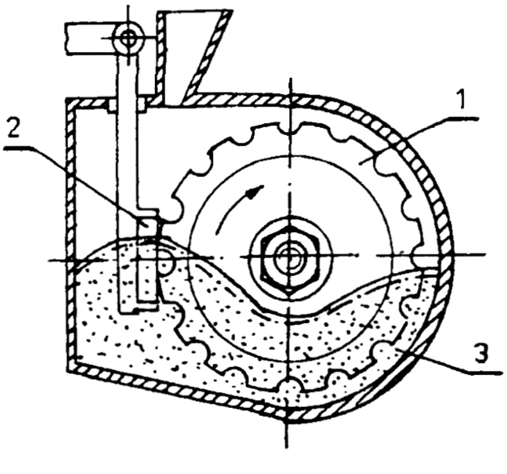

Fig. 3. Scheme of the Haworth-ZIS 116 device: 1 – rubber disc, 2 – tested sample, 3 – abrasive [L. 2]
Rys. 3. Schemat urządzenia Haworth-ZIS 116: 1 – tarcza gumowa, 2 – badana próbka, 3 – ścierniwo [**L. 2**]

PROGRAM AND METHODOLOGY OF RESEARCH

It was assumed that the test conditions should as far as possible reflect the actual operating conditions of a conveyor belt. In order to make the test conditions as close as possible to the real ones, it was assumed that the speed of the relative movement of friction surfaces, unit pressure, and contact geometry would correspond to the conditions prevailing in a moulding sand conveyor.

The following materials were selected for the tests:

- Weldable structural steel S235JR of ordinary quality (used in existing conveyors),
- Constructional steel of increased quality 18G2A,
- AISI 316 acid resistant steel,
- SR3S steel after one-layer hard facing with Durweld 600 electrodes, and
- Hardened steel RAEX 400.

The chemical composition of these materials is shown in **Table 1**. The selected test materials can be used as an alternative in the production of belt conveyors for moulding sand factories. The choice of alternative materials was justified in the following way: 18G2A steel is low alloy steel with increased yield strength, commonly used for welded structures. In this way, the hypothesis is examined whether the increase in the yield strength of steel influences its abrasion resistance in a given environment. The next tested material was AISI 316 steel, which is austenitic, stainless steel, with high resistance to corrosion and high temperature. In a complex process of abrasive wear, corrosion can play a significant role. The other two materials chosen for testing are known for their high abrasion resistance and are widely used for working in soil as well as for channels transporting bulk material. Durweld electrodes have a hardness of 615–650 HBW, depending on the welding conditions and the base material [**L. 6, 7**]. RAEX 400 steel is a manganese hard-wearing steel with a composition similar to 18G2A steel. It has a hardness of 400 HBW. This steel is suitable for plastic processing [**L. 8**].

Table 1. Chemical composition of the materials tested
Tabela 1. Skład chemiczny badanych materiałów

Steel type	C %	Mn %	Si %	P %	S %	Cr %	Ni %	Mo %	Al %	Cu %
S235JR	<0,22	0.65	0.12–0.30	–	–	–	–	–	–	–
18G2A	<0.2	1–1.5	0.2–0.55	<0.40	<0.40	<0.30	<0.30	–	–	<0.30
AISI 316	<0.07	<2.0	<1.0	<0.045	<0.015	16.5–18.5	10–13	2–2.5	–	–
Durweld 600	0.7	0.8	0.3	–	–	–	–	–	–	–
RAEX 400	0.23	1.7	0.7	0.03	0.015	1.5	0.4	0.5	0.06	–

For the needs of the tests, samples of the above materials were made with a thickness of 2 and 3 mm. For the tests, two thicknesses were used, because the available sheet metal sheets were made in various thicknesses. Plates 30 mm wide and 35 mm long were cut from the plates provided for testing. Then, as shown in **Fig. 4**, they were bent, and their edges were chamfered. In the case of the hard-faced element, the padding has been ground to obtain a flat surface. **Fig. 4** shows the sample with dimensions. The padding layer of the hard-faced samples was 1.5–2 mm thick.

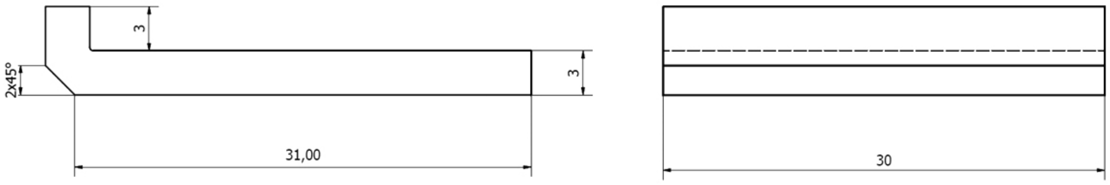

Fig. 4. Scheme of the sample
Rys. 4. Schemat próbki

As a counter-sample, a rubber-textile tape with the designation EP 630/3 was used, which complies with the PN-EN ISO 14890 standard. The longitudinal strength of this tape is 630 N/mm [**L. 9**]. The tape processing was performed in accordance with the guidelines contained in the literature [**L. 9, 10**], and polychloroprene adhesive was used for gluing. The tape of the required length was glued with an overlap. As abrasive medium, moulding sand was used in a recycled way, meaning that new materials were added to the circulating sand to maintain its parameters at a given level [**L. 11**]. The moulding sand consisted mainly of a matrix containing quartz sand, which was rinsed and had a finely defined grain size not exceeding 0.5 mm, as well as additives improving and affecting sand bonding. In the moulding sand, bentonite was used as the binder. The moulding sand also contained hard coal dust, which prevents its sticking to the cast [**L. 12, 13**]. The shape of the quartz grains was slightly rounded. To ensure the same conditions during each test, the sand was taken from one batch of moulding sand. During the tests, constant values of friction speed, pressure, friction path, and the amount of moulding sand added were adopted (**Tab. 2**).

Table 2. Work parameters [L. 1]
Tabela 2. Parametry pracy [**L. 1**]

Independent variable	Symbol	Unit	Value
Relative speed	v	$m \cdot s^{-1}$	2
Pressure	P	MPa	0.02
Total friction path	s	Km	7.2
Amount of moulding sand	D	$Kg \cdot h^{-1}$	20

The speed of conveyor belt was selected according to the information presented in [**L. 5, 9, 14, 15**], and the pressure was averaged, because its value mainly depends on the amount of material that presses on the element at the given moment. The total friction path and the amount of moulding sand were selected as assumptions for the tests.

The test stand specially designed for the needs of these tests was built in the laboratory of the Institute of Machines and Motor Vehicles, Poznan University of Technology. The basic element of this test stand is a short belt conveyor, with the belt supported on the guide plate. A roller moulding sand dispenser and a third-class lever system with sliding weights are mounted above the conveyor. These levers are pivoted on a transverse beam. Samples of the tested materials were mounted on these levers. The sliding weight at the end of each lever allows the pressure of the sample on the conveyor belt to be adjusted. The pulleys have a diameter of 115 mm and a width of 230 mm and are mounted on rolling bearings. The belt of the conveyor has a length of 890 mm, a width of 210 mm, and a thickness of 5 mm. A three-phase asynchronous motor and a belt transmission were used for the conveyor drive. The change of rotational speed is obtained by changing the frequency of the current using the inverter. The dispenser roller is driven by a DC motor with a worm gear reducer. **Fig. 5** presents the layout of the test stand. The machine's construction was designed in a 3D CAD system. **Figure 6** shows a photograph of this test stand.

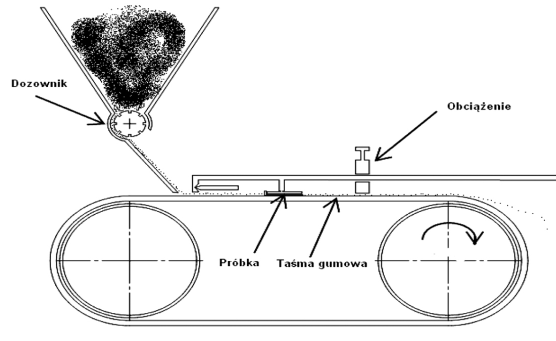

Fig. 5. Scheme of the test stand [L. 1]
Rys. 5. Schemat stanowiska badawczego [**L. 1**]

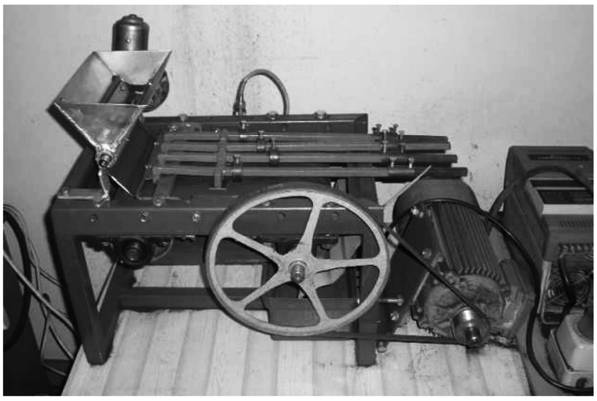

Fig. 6. Complete test stand [L. 1]
Rys. 6. Kompletne stanowisko badawcze [**L. 1**]

The tests were carried out under constant conditions, i.e. constant temperature and air humidity. The moulding sand was sifted through a sieve with a mesh size of 1 mm to reject any type of contamination formed after earlier processing of the moulding sand.

After each successive test, consisting of abrasion of samples at a given speed, under a given load, and on the friction path specified in the testing program, the samples were thoroughly washed in acetone and dried. An ultrasonic washer was used for cleaning, while drying was carried out in a laboratory dryer at a temperature of 80°C. The samples were then carefully weighed using a WPE-30 moisture analyser with a measurement accuracy of 0.01 g. The abrasion tests were repeated 10 times. During the experiment, the amount of material in the dispenser was controlled and kept constant.

TEST RESULTS

The mass loss values obtained from the measurements were subjected to a statistical analysis, which consisted in calculating the mean values of the mass loss and its mean square deviation, according to the dependences presented in the paper [**L. 3**]. The results of these calculations are shown in **Fig. 7**.

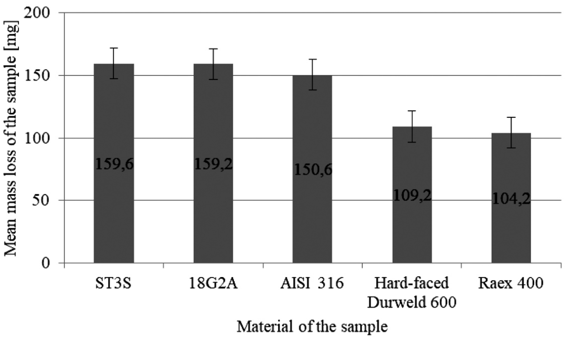

Fig. 7. Mass loss of samples made of selected materials
Rys. 7. Ubytek masy próbek wykonanych z różnych materiałów

The statistical significance of the observed differences in mass loss between each pair of materials was also checked using the Student's t-test. After analysing critical regions at the significance level of $\alpha = 0.05$, it can be concluded that the observed differences in wear intensity for ST3S, 18G2A, and ANSI316 steels are statistically insignificant. Mass losses for samples made of hard-faced steel and RAEX400 steel are significantly lower than in case of the above-mentioned steel by about 32–35%. Differences in wear speed between RAEX steel and hard-faced steel are not statistically significant. The surfaces of the samples after the test were visually similar to the samples after grinding, which is in line with the literature [**L. 16**]. The scratches are parallel to each other and their direction is the same as the direction of belt movement.

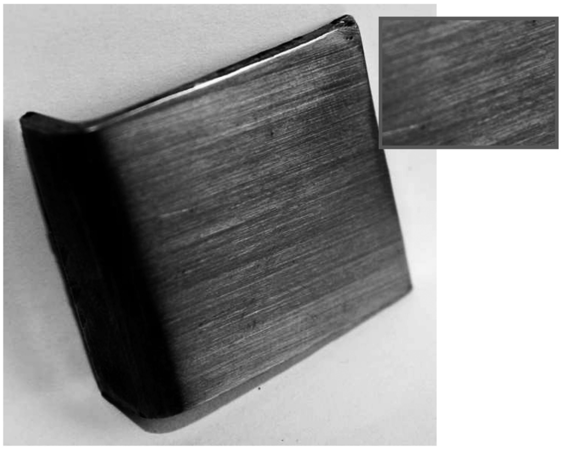

Fig. 8. View of the sample after the test [L. 1]
Rys. 8. Widok próbki po badaniu [**L. 1**]

CONCLUSIONS

The following conclusions can be drawn from the presented research results:

1. An important factor increasing the material's resistance to abrasion in the conditions of the moulding sand conveyor's operation is the hardness of this material. Neither the increase in the yield strength of steel nor the increase in its corrosion resistance was of significant importance. Therefore, the use of more expensive, non-hardened structural steels is not economically justified here.
2. From the presented results of measuring the mass loss of the sample, it is easy to calculate the speed of linear wear on the thickness of the conveyor guard rails, and thus estimate their inter-repair period. This will allow one to estimate how economically justified it is to replace the common steel used here by more expensive abrasive materials. These calculations should take into account the costs of repair downtimes and the costs of repairs themselves. However, these calculations were not covered by this work, as they require additional data specific to a given production plant.
3. The test stand designed and built as part of the work can be further used for many other tests in the field of abrasiveness of construction materials, in particular, materials suitable for belt conveyors, including the materials for belts.
4. In further research on the problem undertaken in this work, it is necessary to take into account the change in the shape of the guard rail, leading to the optimisation of the pressure distribution, as well as the possibility of using pneumatic cushions under the belt to remove quartz grains from the gap and reduce friction forces.
5. The development of the test method proposed in the paper should take into account the possibility of introducing the measurement of friction force, which will allow one to investigate the correlation between work of friction and the speed of wear, and consequently improve the mathematical model of the abrasive wear process, which is the main scientific goal of this type of work.

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