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ANALYSIS OF TENSILE PROPERTIES OF WORN FABRIC CONVEYOR BELTS WITH RENOVATED COVER AND WITH THE DIFFERENT CARCASS TYPE

ANALIZA WŁAŚCIWOŚCI WYTRZYMAŁOŚCIOWYCH ZUŻYTYCH TKANINOWYCH TAŚM PRZENOŚNIKOWYCH Z RÓŻNYMI TYPAMI RDZENIA PO RENOWACJI GÓRNEJ OKŁADKI

Conveyors are the means of transportation used in many industries. The load-bearing and tractive component of a belt conveyor is a conveyor belt which consists of a carcass and cover layers. During an operation, belts are exposed to loads that cause damage to the belts. It is therefore necessary to ensure that a conveyor belt possesses required mechanical properties during the transport of material. The key mechanical properties of a conveyor belt are tensile properties. They are significantly affected by the fabric carcass of a conveyor belt. The tensile properties of conveyor belts are largely affected by the carcass materials. They are also affected by the types of fibres in the longitudinal (warp) and transverse (weft) directions of the fabric carcass because the carcass transfers all tensile stresses of the conveyor belt. A fabric conveyor belt is regarded as a composite material, consisting of the carcass (polyamide P and polyamide-polyester EP) and the cover layers. The costs of a conveyor belt represent 10-30 % of the price of the entire conveyor. It is therefore reasonable to prefer only those conveyor belts that show the properties prescribed by relevant norms. The subject of the article is worn conveyor belts with renovated top cover (renovated conveyor belts). The tensile properties are used to assess the suitability for further use of renovated conveyor belts in practice. The article presents the analysis of tensile properties of renovated fabric conveyor belts in relation to the carcass type. The observed results were compared applying the DOE method, regression and correlation analysis, and the method of statistic induction. All the conclusions, made based on the above-listed methods, are identical for the examined tensile properties. The results indicate that the examined tensile properties of conveyor belts have not undergone any significant change after the renovation of the top cover layer.

Keywords: *tensile properties, worn conveyor belt, renovation of top cover, carcass type.*

Przenośniki taśmowe znajdują zastosowanie jako urządzenia transportowe w wielu gałęziach przemysłu. Nośnym i pociągowym elementem przenośnika taśmowego jest taśma transportowa, która zbudowana jest z rdzenia i okładek. Podczas pracy, taśmy narażone są na obciążenia, które prowadzą do ich uszkodzenia. Dlatego konieczne jest aby taśma transportująca materiał posiadała wymagane właściwości mechaniczne. Kluczowymi właściwościami mechanicznymi taśmy przenośnikowej są właściwości wytrzymałościowe. Zależą one w dużym stopniu od tkaninowego rdzenia taśmy, a w szczególności od rodzaju materiałów, z których jest zbudowany, oraz typu włókien wchodzących w skład jego osnowy (biegnących w kierunku wzdłużnym) i wątku (w kierunku poprzecznym), jako że to właśnie rdzeń przenosi wszystkie naprężenia rozciągające taśmy przenośnika. Tkaninową taśmę transportową uważa się za materiał kompozytowy, składający się z rdzenia (poliamid P i poliamid–poliester EP) oraz warstw wierzchnich (okładek). Koszty taśmy stanowią 10–30% ceny całego przenośnika, dlatego do użycia powinno dopuszczać się jedynie takie taśmy przenośnikowe, które wykazują właściwości określone w odpowiednich normach. Przedmiotem artykułu są zużyte taśmy przenośnikowe z odnowioną górną okładką (odnowione taśmy przenośnikowe). Właściwości wytrzymałościowe wykorzystano do oceny przydatności odnowionych taśm do dalszego wykorzystania w warunkach praktycznych. W artykule przedstawiono analizę właściwości wytrzymałościowych odnowionych taśm tkaninowych w funkcji typu rdzenia. Zaobserwowane wyniki porównano stosując metodę DOE, analizę regresji i korelacji oraz metodę indukcji statystycznej. Wszystkie wnioski uzyskane w oparciu o wyżej wymienione metody są identyczne dla badanych właściwości wytrzymałościowych. Wyniki wskazują, że badane właściwości wytrzymałościowe taśm przenośnikowych nie ulegają istotnej zmianie po renowacji górnej okładki.

Słowa kluczowe: *właściwości wytrzymałościowe, zużyta taśma przenośnikowa, renowacja okładki górnej, typ rdzenia.*

1. Introduction

Belt conveyors have modular designs and are assembled using individual structural components in order to create a transport route of the required length. Such length is limited by the strength of the used type of the belt and by the performance of the drive station. Selecting an appropriate type of belt and possessing the information on its properties may positively affect the conveyor structure and operation.

The external load applied to a conveyor belt induces certain changes in its shape and dimensions; this is referred to as deformation. The changes in shapes or dimensions caused by the effects of an external force are expressed by mechanical properties of conveyor belts.

Mechanical properties are specifically determined in various regulations (technical and technological) and the requirements for conveyor belts are based on particular desired applications. Investigation of these properties is therefore very beneficial for users as well as manufacturers. The investigation thereof has been described by many authors. Kessentini et al. investigated the behaviour of composite polyester/polyamide railway fabric conveyor belts covered by rubber plies after water penetrated inside. They performed hygroscopic gravimetric experiments to assess the moisture diffusion coefficients; gravimetric experiments were performed separately for rubber cover layers, fabric carcasses, and belt specimens [22]. Wong et al. investigated the effects of moisture absorption on the residual tensile strength of uncorrected grooved and double-coated corrected carbon/epoxy composites [29]. Hakami et al. investigated the wear, surface roughness, and temperature increase of styrene-butadiene rubber, natural rubber, and nitrile-butadiene rubber when shifted over abrasive materials of various sizes, with normal load variation. The properties of rubber, such as tensile strength and elongation at break were regarded as input parameters [19]. In another paper, Hakami et al. investigate rubber wear rate and mechanisms and the related affecting parameters based on the data published in the literature. Wear, fatigue and creation of rollers dominate the wear mechanisms that are affected by the load, motion velocity, hardness, and abrasion. Detailed correlations between the affecting parameters and their impact on the rubber wear rate were determined [20]. Alajmi and Shalwan investigated the correlation between mechanical properties of fillers/epoxy composites and their tribological behaviour. Tensile, hardness, wear, and friction tests were conducted for neat epoxy composites, graphite/epoxy composites, and data palm fibre/epoxy composites with or without graphite. The correlation was made between the tensile strength, modulus of elasticity, elongation at break, and hardness, as individual or combined factors, with the specific wear rate and coefficient of friction of composites [1].

Fedorko et al. describe in their papers [6,7,8,9] a novel and still unpublished method of analysing failures of fabric conveyor belts made loaded by the tensile force [15]. This team investigated the properties of smooth conveyor belts by conducting a tensile test aimed at examining the behaviour of internal structures of belt specimens. They applied the metro-tomographic analysis to monitor the behaviour of internal structures of belt specimens exposed to a load. They used the measurements of distances between individual fibres in the warp and weft of the carcass and apply a simple analysis of the extent of the observed defects. The presented results prove that the method of industrial tomography clearly identifies failures of conveyor belt carcasses and facilitates identification of individual fibres, puncture, and separation of individual layers [16,17]. In his paper [18], Fedorko describes the application of FEM-based simulation tools within his research and analyses. Mazurkiewicz claims that extensive, unanalysed reduction of specimen surface during a test significantly affects the accuracy of the a structure model analysed applying the FEM. His article [24] provides the analysis of this problem with regard to modelling the adhesive joining of rubber materials and rubber seal which represents the method to be adopted for identification of strength characteristics of analysed materials, thus eliminating the inaccuracy of the FEM model.

The results are often evaluated by applying the DOE method. This method was used to test the tension of rubber conveyor belts [3] and identify the factors affecting the value of the dynamic impact of a load of conveyor belts [4]. The results of the tests of rubber products, in terms of their quality, aimed at identifying the limit value of impact load, are presented by Ambrisko et al. in the paper [5]. The investigation of the resistance of conveyor belts to punctures and longitudinal slitting is described in the paper by Bajda [9].

Moezzi et al. investigated industrial fabrics used in fabric conveyor belts. They observed an interesting mechanism of degradation of fabrics made of nylon 66 after exposure to the UV radiation at various exposure times; this was confirmed by the results observed for mechanical properties of the specimens. The results of this study may be used in industrial applications of belt conveyors made of nylon 66, exposed to the solar UV radiation [25]. In his paper [11], Barburski analysed mechanical properties of conveyor belts in three main production stages: raw fabric, fabric impregnated with latex, and a conveyor belt. He observed that the differences in mechanical properties of products in individual stages of conveyor belt production depend on the number of the points of intersection in fabric threads.

In his paper [2], Ambrisko describes testing the cover layers of conveyor belts aimed at the identification of abrasion resistance and hardness of cover layers as well as the changes therein caused by natural ageing. The impact of natural ageing on the strength parameters of steel cord conveyor belts are described in the paper by [10] Bajda and Hardygora. In his paper [23] Long et al. describes the investigation of the effects of various factors on the strength of joints in steel-cord conveyor belts; they also examined contact between steel cords and rubber. The paper by Blazej et al. [12] describes the monitoring of creep and stress relaxation occurring in two different types of thermally vulcanised joints in fabric conveyor belts.

Saderova presents in her paper the experimental results of the tensile properties of rubber-fabric composites in relation to the carcass type [27]. Petrikova et al. investigate mechanical properties of conveyor belt specimens in tensile tests conducted at different load speeds; relaxation tests were carried out while measuring also the abrasion index [26]. Harsha investigated the mechanical and tribological properties of various injection-formed polyaryletherketones and their composites. He also examined the tensile strength, modulus of elasticity, elongation at break, flexural strength, flexural modulus, hardness and impact strength [21]. Bojic et al. also tested tensile properties of two plastic woven belts (maximum force, maximum expansion, force at break, and elongation at break) and based on the obtained results they defined a belt that is more suitable for applications in conveyors [14].

The methodology of testing conveyor belts, especially their service life affected by the wear of cover layers, is discussed by authors [28, 8, 13]. The renovated conveyor belts are discussed in papers [6, 7]. These papers present the evaluation of the belt damage degree conducted while applying the logistic regression.

2. Material and methods

2.1. Problem formulation

The fundamental structural components of a conveyor belt include carcass (fabric, steel) and cover layers. Cover layer thickness is affected by the properties of the transported material.

For the purpose of accurate identification of mechanical properties of conveyor belts, a whole conveyor belt (including individual components) must be subjected to tests. Mechanical tests should be conducted and evaluated considering the fact that a conveyor belt is made of several different types of materials. Especially rubber composites, forming the cover and adhesive layers of a conveyor belt, show more complex processes of wearing or deformation during the mechanic stress [20].

The purpose of the experiments was to assess selected mechanical properties of worn fabric conveyor belts with renovated top cover (renovated conveyor belts).

The renovated conveyor belt shall mean a worn belt which has been decommissioned and its top cover layer has been subsequently renovated.

2.2. Conveyor belt specimens

The carcass of a fabric conveyor belt consists of the load-bearing carcass with several fabric plies that are coated with a special rubber compound that ensures adhesion between the plies.

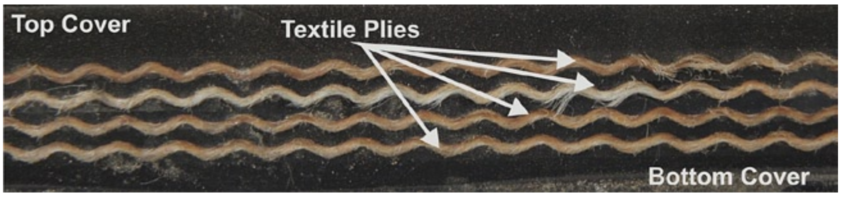

Fig. 1. Fabric conveyor belt (composite)

Carcasses are reinforced with various types of natural and synthetic materials. Most frequently used are conveyor belts with polyamide (P) or polyamide-polyester (EP) carcasses. A polyamide (P) fabric carcass contains polyamide fibres in the weft and in the warp. A polyamide-polyester (EP) carcass consists of polyamide fibres in the weft and polyester fibres in the warp.

- Polyamide is a fully synthetic fibre of good elasticity, high resistance to dynamic stress, resistance to moisture and chemicals. It shows high strength, good fatigue values, but high elongation.
- Polyester is a fully synthetic fibre of good tensile properties, resistance to moisture, acids, and bases. Compared to polyamide, it shows lower strength and lower elongation.

Selected properties of polyamide and polyester are listed in Table 1.

Table 1. Comparison of selected properties of polyamide and polyester

Material	Polyamide (P)	Polyester (E)
Fibre strength [N.mm^2]	740-910	830-970
Breaking force (wet) [%]	65-80	60-70
Specific weight [gcm^{-2}]	1.14	1.38
Elongation at break [%]	12-18	10-15
Elongation at break (wet) [%]	15-25	12-18
Permanent elongation [%]	0.5-3.0	0.3-0.9
Elastic elongation [%]	0.6-1.5	0.5-1.2
Maximum elongation at 1T [%]	1.5-3.0	0.8-2.5

When compared to a polyamide fibre, a polyester fibre shows lower ductility and higher shape stability, and its elongation at use is lower. It is beneficial to use the combination of polyester fibres in the warp and polyamides fibres in the weft as this combination ensures small extension in the longitudinal direction, but good troughability and flexibility of the belt in the transverse direction. When compared to polyamides, polyesters show certain disadvantage-higher density which is manifested by a higher belt weight.

The experiment was carried out using the specimens of fabric conveyor belts with two types of carcasses (P, EP), three different strength values (800; 1,000; and 1,250 N.mm^{-1}), and different numbers of fabric plies (3 and 4). 5 specimens were prepared from each type of conveyor belt.

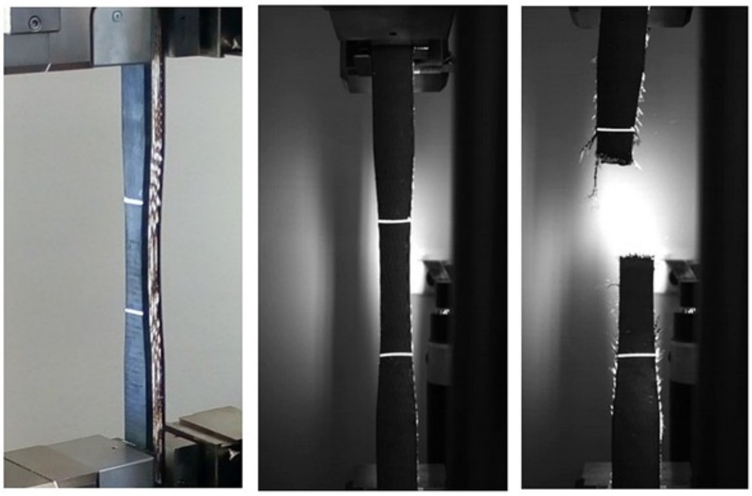

Fig. 3. Fixing and testing the specimen

The tested specimens, in the shape of a double-sided blade (Fig. 2), were cut out from the conveyor belt applying the prescribed method. The test pieces were cut out parallelly to the belt axis, in the minimum distance of 50 mm from the belt edge. The specimens have to be cut out perpendicularly to the belt surface and must not contain any joints. The specimen length was 400 mm; the width was 35 mm; and the thickness was determined by the thickness of the conveyor belt from which the particular specimen was cut out. On the prepared specimens, two contrast lines (reference lines −1) were marked in the mutual distance of 100 mm, perpendicularly to the specimen axis. The lines were marked symmetrically to the specimen centre.

Prior to the measurements, the specimens were subjected to conditioning (ISO 18573 standard).

2.3. Experiment execution

The experimental measurements were carried out using the Zwick Roell Z250 testing machine. It is a stationary machine with a linearly growing load. The Z250 machine provides a versatile environment for all kinds of axial tests at lower displacement rates. In the experiment, the testing machine was used in tensile tests. The measurement procedure was as described below.

In the first step, the testing machine was launched together with the operating software for tensile tests for a particular type of the tested materials. In the following step, the test parameters were set, in compliance

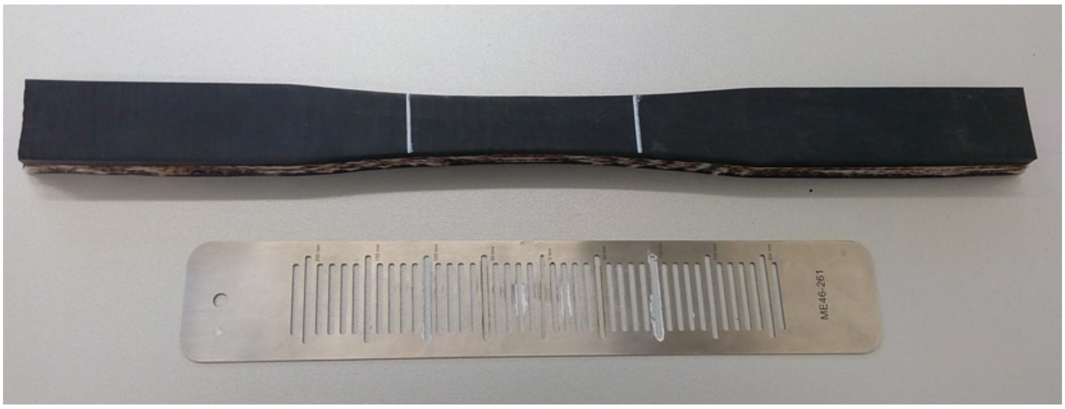

Fig. 2 Test specimen

with the EN ISO 283 standard (velocity of 100 mm.min^{-1}). Subsequently, the specimen was fixed in pneumatic jaws (Fig. 3). The test piece dimensions were entered in the software (measured thickness, width, and tested length). This was followed by performing the measurements that included continuous stretching of the test specimen (until the specimen was exposed to the reference force, or until the specimen rupture) and recording the measured data. After the measurements were completed and the values were recorded, the specimen was removed from the machine and a new specimen was inserted. If a test specimen showed no disturbance between the reference lines, or if the test piece was sliding between the jaws during the test, the specimen was excluded. Each valid measurement with a particular specimen type was repeated three times (Fig. 4).

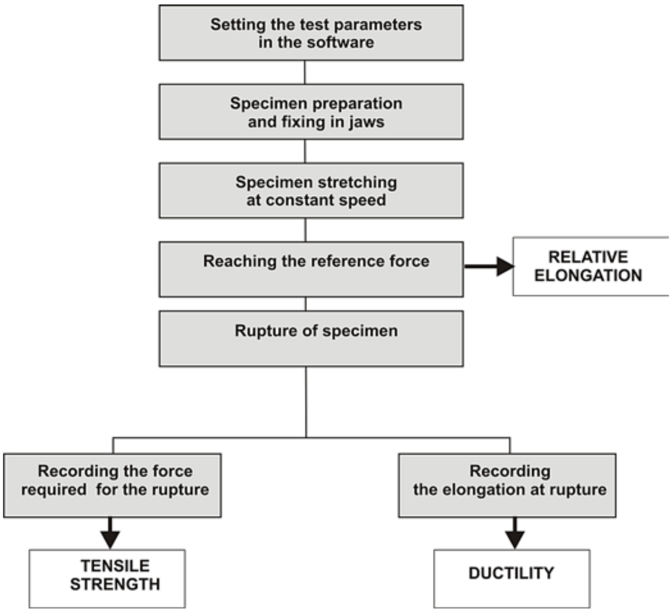

Fig. 4. Measurement scheme

3. Theory/calculation

The strength of conveyor belts necessary for a particular operation is determined using the strength calculation. Total dynamic resistance must be identified for both strands (upper and lower) of the belt conveyor; this equals the total circumferential force on the drive pulley at a stable operation of the conveyor. The magnitude of the total circumferential force can be used to calculate the magnitudes of tensile forces in the belt. They may subsequently be used to identify the necessary belt strength. The calculation of the conveyor belt strength is made while considering its inhomogeneous structure. Considerations are only given to the belt carcass (fibres of the tractive component) because the strengths of other belt parts are relatively small compared to the carcass strength. The strength of the belt is expressed by the force applied to 1 meter of its width because the size of the area of the load-carrying cross-section, especially when a fabric ply is used, can only be identified with high inaccuracy. The belt inspection is carried out while considering only the tensile stress; other stresses are considered by a relatively high safety.

3.1. Methods of experimental research – the test of conveyor belts

The tests of selected mechanical properties (tensile properties) of conveyor belts were carried out pursuant to specified standards. These tests were divided into groups and performed as described in Table 2.

3.1.1. Relative elongation at reference load

The percentage of relative elongation was identified using the following formula:

$$\varepsilon_R = 100\frac{(l_R - l_1)}{l_1} \tag{1}$$

where:

ε_R is elongation of the test piece [%];

l_1 is the initial length (initial distance between the reference lines) [mm]; and

l_R is the length recorded at the reference load of the test piece (final distance between the reference lines) [mm].

3.1.2. Tensile strength

The tensile strength represents the maximum potential stress in the stretched material which the material as a whole is able to resist right before the rupture.

It was calculated using the following formula:

$$F_S = \frac{F_R}{b}, \tag{2}$$

where:

F_S is the tensile strength [N.mm^{-1}];

F_R is the force loading the test piece at the moment of rupture [N]; and

b is the width of the test piece [mm].

3.1.3. Ductility

Ductility is the relative longitudinal elongation of the test piece at the moment of rupture. The percentage of ductility was calculated using the following formula:

$$\varepsilon = 100\frac{(l_2 - l_1)}{l_1}, \tag{3}$$

Table 2. Tensile properties of conveyor belts

Test name	Test mechanism
Relative elongation at reference load	It was performed during the measurement of tensile strength. A test piece was exposed to the tensile force at constant velocity and records were made on the elongation of the working section when reaching the reference load (reference force).
Tensile strength	A test piece was exposed to the tensile force at constant velocity until the rupture occurred and records were made on the required force.
Ductility	It was performed during the measurement of tensile strength. A test piece was exposed to the tensile force at constant velocity until the puncture occurred and records were made on the elongation of the working section at the moment of rupture.

where:

ε is the ductility [%];

l_1 is the initial length (initial distance between the reference lines) [mm];

l_2 is the length recorded right before the rupture of the test piece (final distance between the reference lines) [mm].

3.2. Methods of evaluation and comparison

The Design of Experiments (DOE) method facilitates better understanding and improving technological and laboratory processes. This method enables identification of the process-entering factors with decisive effects on the monitored outputs (output factors or output variables). The assessment of the importance of different effects of factors and identification of optimal conditions were facilitated by the execution of well-prepared experiments. The evaluation of experimental results was carried out using the statistical methods that enable the assessment of whether a change in the monitored output variable was caused by the effects of input factors.

There are different types of experiment planning. The experiment described herein was planned to apply the full three-factorial design in which each considered factor acquired two levels: low „-” and high „+”. The effect of the monitored factor on the output variable represented the difference between the average temperatures of the output variable at the low and high levels of the given factor.

The description and comparison of the monitored variables were carried out applying the *basic statistical methods*, including the estimation theory, testing statistical hypothesis, regression and correlation analyses. The predetermined statistical hypotheses were tested by parametrical and non-parametrical tests (one-sample t-test, non-parametric Wilcoxon one-sample test, paired t-test, paired Wilcoxon test, Shapiro-Wilk test for normality, one-way ANOVA test, Kruskal-Wallis test, etc.). The decision-making on accepting or rejecting the null hypothesis was carried out using the p-value. If the p-value was less than the significance level α, then the null hypothesis was rejected. If the p-value was more than, or equal to, the significance level α, the null hypothesis was accepted.

The purpose of the *regression analysis* is to evaluate the existence of relationships between two or more variables and find a suitable regression model for a particular relationship. General considerations were made while presuming a single measurable continuous explanatory (output) variable Y and k explanatory independent variables X_i for $i=1, 2,\dots, k$. The considered conventional multiple regression model was as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \varepsilon , \tag{4}$$

where β_0 and β_i for $i=1, 2,\dots, k$ are the regression model parameters and ε is the random error.

The statistical significance of the model (or of individual parameters) was verified applying the F-test of statistical significance of the model (or the test of the statistical significance of the regression parameter). The quality of the regression model was verified using the coefficient of determination R^2. The obtained results were evaluated and compared using the R and Minitab software products.

4. Result and discussion

The experimental research was carried out with the following objectives:

- Compare the tensile properties (relative elongation at the reference load, tensile strength or ductility) of the renovated conveyor belt with the reference values obtained for new conveyor belts.
- Identify which of the input variables (carcass type, number of fabric plies, and conveyor belt strength) affect the output vari-

Table 3. Basic numerical characteristics of output variables

Carcass type	P						EP					
Strength	**800**		**1,000**		**1,250**		**800**		**1,000**		**1,250**	
Number of plies	**3**	**4**	**3**	**4**	**3**	**4**	**3**	**4**	**3**	**4**	**3**	**4**
Y_1												
Average	1.52	1.40	1.77	1.63	2.09	1.81	1.06	0.90	1.10	0.99	1.27	1.01
Maximum	1.80	1.70	2.20	2.00	2.40	2.20	1.30	1.20	1.40	1.30	1.50	1.30
Minimum	1.30	1.00	1.50	1.30	1.70	1.50	0.80	0.70	0.90	0.80	1.00	0.80
St.deviation	0.14	0.18	0.19	0.20	0.24	0.20	0.14	0.14	0.15	0.14	0.15	0.15
$Yref_1$	1.50	1.41	1.70	1.60	2.10	1.80	1.00	0.92	1.10	1.00	1.20	1.00
Y_2												
Average	906.0	978.2	1195.6	1230.6	1466.9	1517.9	926.6	991.4	1181.3	1236.8	1489.9	1551.9
Maximum	979.0	1029.0	1238.0	1300.0	1533.0	1660.0	996.0	1083.0	1270.0	1334.0	1564.0	1628.0
Minimum	848.0	911.0	1110.0	1169.0	1405.0	1417.0	835.0	880.0	1107.0	1122.0	1433.0	1471.0
St.deviation	33.07	30.88	35.18	37.36	34.88	64.59	41.28	62.30	41.90	62.47	44.21	52.58
$Yref_2$	899.0	988.0	1210.0	1232.0	1455.0	1518.0	942.0	991.0	1190.0	1228.0	1473.0	1559.0
Y_3												
Average	21.71	21.76	22.81	22.86	24.00	24.10	17.81	18.24	18.57	18.62	19.52	19.57
Maximum	23.00	24.00	25.00	25.00	26.00	26.00	20.00	20.00	20.00	20.00	21.00	21.00
Minimum	20.00	20.00	21.00	21.00	22.00	22.00	16.00	16.00	17.00	17.00	18.00	18.00
St.deviation	0.96	1.14	1.40	1.15	0.95	1.14	1.17	1.26	1.08	1.02	0.98	1.08
$Yref_3$	22.00	22.00	22.10	2.50	23.80	24.50	18.20	18.50	18.90	19.00	19.40	19.20

ables (relative elongation at the reference load, tensile strength, or ductility) of the renovated conveyor belt.

- Create regression models of the relationships between the output variables and the input variables of the renovated conveyor belt.
- Compare tensile properties of the renovated conveyor belts with polyamide or polyamide-polyester fabric carcasses.

4. 1. Comparison of tensile properties with the reference values

The experimental research was carried out using 60 test specimens extracted from renovated conveyor belts. The experiment was carried out using renovated rubber-textile conveyor belts with the polyamide or polyester carcass of various strengths (800 $N.mm^{-1}$; 1,000 $N.mm^{-1}$; or 1,250 $N.mm^{-1}$) and with 3 or 4 textile plies. The investigation was concentrated on three basic tensile properties (output variables): relative elongation at the reference load Y_1 [%], tensile strength Y_2 [Nmm^{-1}], ductility Y_3 [%].

The reference value $Yref_z$, z=1,2,3 shall mean the value obtained from the measurements of the investigated properties Y_z (z=1,2,3) for three specimens of new (unused) conveyor belts. The comparison of tensile properties of specimens of renovated conveyor belts with the reference values was carried out applying the basic methods of statistical induction - testing statistical hypotheses. Basic numerical characteristics of the investigated properties of renovated conveyor belts (the output variables) and the relevant reference values are listed in Table 3.

The normality of the data set of renovated conveyor belts was verified applying the Shapiro-Wilk test of normality. The null hypothesis is that the sample come from a Normal distribution. If p-value < α, the null hypothesis is rejected. For output variable Y_1 (relative elongation) and Y_2 (tensile strength), the normality requirement was met in all the cases (Table 4).

The comparison of the measured tensile properties with reference values was carried out applying the parametric one-sample t-test or non-parametric Wilcoxon one-sample test (in the case that the normality requirement is not met).

The results of the comparison indicate that there are no statistically significant differences between the measured values of tensile properties (Y_z , z=1,2,3) and the reference values $Yref_z$, z=1,2,3 (p-value>α). The resulting p-values of the tests are listed in Table 5.

The following sections will deal with the values obtained exclusively from the specimens of renovated rubber-textile conveyor belts.

4.2. DOE method

The purpose of the experiment was to identify which is the input factors (conveyor belt strength A, number of fabric plies B and carcass type C) have statistically significant effects on the value of the output factor Y_z, z=1,2,3 (relative elongation at the reference load Y_1 [%], tensile strength Y_2 [Nmm^{-1}], ductility Y_3 [%]).

All input factors were tested at two different levels. The experiment was carried out using two types of renovated rubber conveyor belts (polyamide and polyester) with the strengths of 800 $N.mm^{-1}$ or 1,250 $N.mm^{-1}$ and with 3 or 4 fabric plies. The levels of individual factors are listed in Table 6.

Each experiment was conducted twice and the evaluation was carried out using the average value of the output variable. The experiment was evaluated considering three main factors (A, B and C) and second-order interactions (AB, AC, and BC). The effects of the main factors and interactions for all three output variables are listed in Table 7. The significance of the individual effects of the factors or interactions on the output variables was tested by the t-test and by the determination of the p-value. Statistically significant effects on the output variable were observed for those main factors, or interactions, for which the p-value < 0.05*.

Table 4. Shapiro-Wilk test of normality (α=0.05)

Carcass type	P						EP					
Strength	800		1,000		1,250		800		1,000		1,250	
Number of plies	3	4	3	4	3	4	3	4	3	4	3	4
Y_1												
p-value	0.259*	0.064*	0.219*	0.193*	0.105*	0.159*	0.188*	0.076*	0.060*	0.113*	0.074*	0.115*
Y_2												
p-value	0.600*	0.212*	0.142*	0.698*	0.145*	0.243*	0.687*	0.190*	0.906*	0.090*	0.060*	0.061*
Y_3												
p-value	0.006	0.092*	0.010	0.081*	0.071*	0.012	0.037	0.082*	0.002	0.015	0.019	0.004

*Note: *p-value> α*

Table 5. Test results (one sample t-test, Wilcox one-sample test, α=0.05)

Type of carcass	P						EP					
Strength	800		1,000		1,250		800		1,000		1,250	
Number of plies	3	4	3	4	3	4	3	4	3	4	3	4
Y_1												
p-value	0.530*	0,906*	0.105*	0.510*	0.784*	0.831*	0.070*	0.534*	0.882*	0.651*	0.055*	0.673*
Y_2												
p-value	0.345*	0,161*	0.075*	0.863*	0.135*	0.997*	0.102*	0.978*	0.352*	0.528*	0.096*	0.541*
Y_3												
p-value	0.177*	0,348*	0.080*	0.171*	0.345*	0.203*	0.132*	0.413*	0.673*	0.103*	0.569*	0.232*

*Note: *p-value> α*

Table 6. Levels of main input factors

Factor level	**Main input factors**		
	Strength [N.mm^{-1}]	**Number of fabric plies [m]**	**Carcass type**
	A	B	C
Low (-)	800	3	P
High (+)	1,250	4	EP

The analysis of the results indicates that all three main factors (A, B, and C) have statistically significant effects on the relative elongation (Y_1) (p-value < α).

Two main factors: factor A (strength) and factor B (number of fabric plies) have statistically significant effect on the tensile strength (Y_2).

Two main factors: factor C (carcass type) and factor A (strength) have statistically significant effects on ductility (Y_3).

4.3. Regression and correlation analysis

Monitoring the effects of the input variables (conveyor belt strength, number of fabric plies and carcass type) on the output variables was based on the following model:

$$Y_z = f\left(STRENGTH, NUMBER\ OF\ PLIES,\ CARCASS\ TYPE\right), \text{ for } z = 1,2,3 \quad (5)$$

where Y_1 is the relative elongation at the reference load [%], Y_2 is the tensile strength [Nmm^{-1}], and Y_3 is the ductility [%].

The point estimate of the regression model has the following form:

$$Y_z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \text{ , for } z = 1,2,3 , \quad (6)$$

where $\beta_0, \beta_i, i=1,2,3$ are the parameters of the models; X_1 is the strength; X_2 is the number of fabric plies; and X_3 is the carcass type (X_3=0, if the carcass type is P, X_3=1, if the carcass type is EP). Mutual relationships were identified considering the average values of individual variables. The model parameters were identified applying the method of least squares.

The most optimal regression model of the relationship between the variable Y_1 and the input variables was the following model (type I):

$$Y_1 = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3. \quad (7)$$

The analysis of the results indicated that all input variables (X_1, X_2 and X_3) have statistically significant effects on the relative elongation (Y_1) (p-value < α).

For the variable Y_2, the best regression model is as follows (type II):

$$Y_2 = b_0 + b_1 X_1 + b_2 X_2. \quad (8)$$

Two input variables have statistically significant effects on the tensile strength (Y_2): the strength (X_1) and the number of fabric plies (X_2).

As to the variable Y_3, the best regression model is as follows (type III):

$$Y_3 = b_0 + b_1 X_1 + b_3 X_3. \quad (9)$$

The analysis of the results indicated that the strength (X_1) and the carcass type (X_3) have statistically significant effects on ductility (Y_3).

The point estimates of regression model parameters, statistical significance of the parameters (p-value), coefficient of determination, and p-value of the model are listed in Table 8.

All parameters of the examined regression models, as well as the given regression model, are statistically significant (p-value < α). The values of coefficients of determination R^2 indicate that the quality of the regression model is high.

Table 7. Effects of the main factors and interactions of second-order (α =0.05)

Output variable		**A**	**B**	**C**	**AB**	**AC**	**BC**
Y_1 - Relative elongation	effect	0.320	-0.205	-0.640	-0.065	-0.160	-0.005
	p-value	0.030*	0.046*	0.015*	0.144	0.060	0.795
Y_2 - Tensile strength	effect	556.10	62.52	22.66	-5.98	5.78	0.88
	p-value	0.005*	0.047*	0.127	0.416	0.426	0.878
Y_3 - Ductility	effect	1.905	0.145	-4.120	-0.070	-0.385	0.095
	p-value	0.040*	0.440	0.019*	0.664	0.192	0.571

Table 8. Point estimates of regression models

Output variable	**Model parameters**				**R^2**	**p-value**
	b_0	b_1	b_2	b_3		
Y_1 - Relative elongation	1.545	0.001	-0.162	-0.645	95.44	2.10^{-10*}
p-value	2.10^{-4*}	1.10^{-3*}	2.10^{-2*}	2.10^{-6*}		
Y_2 - Tensile strength	-216.622	1.234	52.758	-	99.48	2.10^{-11*}
p-value	9.10^{-4*}	6.10^{-12*}	5.10^{-4*}	-		
Y_3 - Ductility	18.538	0.004	-	-4.15	99.30	2.10^{-10*}
p-value	2.10^{-12*}	6.10^{-7*}	-	1.10^{-10*}		

*Note: * p-value < α*

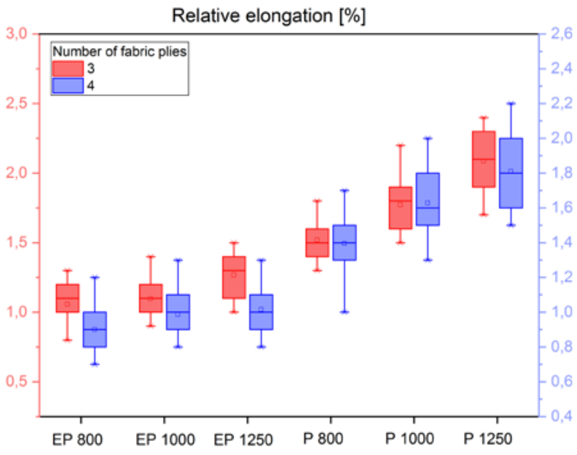

Fig. 5 Boxplot – Relative elongation

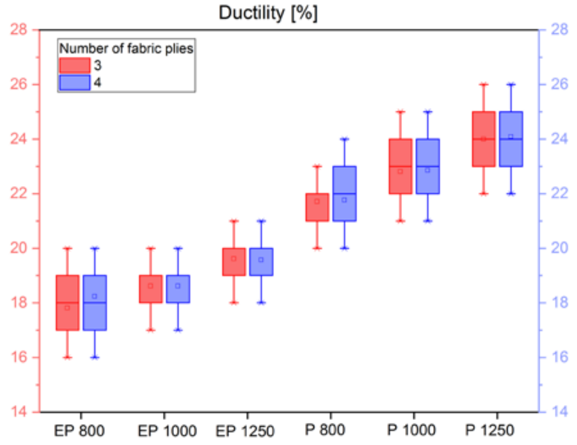

Fig. 6 Boxplot – Tensile strength

4.4. Comparison of tensile properties

This section presents the comparison of tensile properties obtained from the specimens of renovated rubber-textile conveyor belts with the polyamide carcass and the specimens with the polyamide-polyester textile carcass. The basic numerical characteristics of the investigated properties are listed in Table 3. Graphical representations of data sets are shown in Fig. 5 – 7.

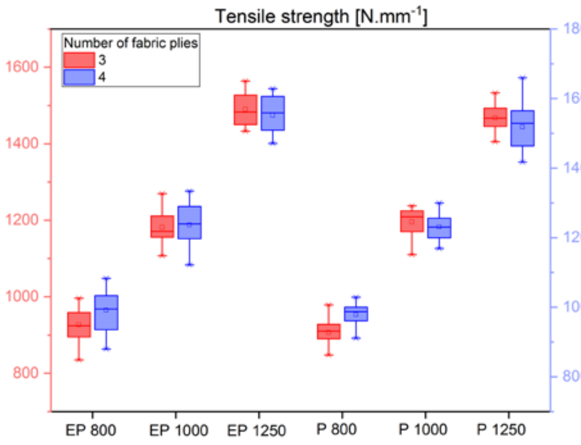

Fig. 7 Boxplot – Ductility

The paired comparison of the measured values of individual output variables was carried out applying the paired t-test, or the non-parametric Wilcoxon paired test. The comparison of the three data sets was carried out applying the ANOVA method, or the Kruskal-Wallis test. The test results are listed in Tables 9 to 11. The statistic testing was focused on the following three areas:

- I - effects of the number of fabric plies on the values of individual output variables, on condition that carcass types and strengths are identical (paired t-test or Wilcoxon paired test);
- II - effects of the carcass type on the values of individual output variables, on condition that the strengths of conveyor belts and numbers of fabric plies are identical (paired t-test or Wilcoxon paired test); and
- III - effects of the strength on the values of individual output variables, on condition that carcass types and numbers of fabric plies are identical (ANOVA or Kruskal-Wallis test).

The analysis of the results of Testing I (Table 9) indicates that with identical carcass types (either P or EP) and identical conveyor belt strengths, the number of fabric plies (3 or 4) has a statistically significant effect on the output variable Y_1 (relative elongation) and the output variable Y_2 (tensile strength). On the other hand, it seems that the number of fabric plies has no statistically significant effect, under the given conditions, on the output variable Y_3 (ductility).

The analysis of the results of Testing II (Table 10) indicates that with identical conveyor belt strengths and identical numbers of fabric plies, a carcass type (either P or EP), has a statistically significant effect on the output variable Y_1 (relative elongation) and the output

Table 9. Results of Testing I – number of fabric plies (α =0.05)

Variable	**p-value**	**P800/3** **P800/4**	**P1000/3** **P1000/4**	**P1250/3** **P1250/4**	**EP800/3** **EP800/4**	**EP1000/3** **EP1000/4**	**EP1250/3** **EP1250/4**	**Stat. significance**
Y_1	p-value	2.10^{-2}	2.10^{-2}	2.10^{-4}	8.10^{-4}	2.10^{-2}	2.10^{-4}	**Stat. significant**
Y_2	p-value	7.10^{-9}	3.10^{-3}	3.10^{-3}	3.10^{-4}	2.10^{-3}	2.10^{-4}	**Stat. significant**
Y_3	p-value	0.969	0.907	0.646	0.293	0.927	0.970	Stat. insignificant

Table 10. Results of Testing II – carcass type (α =0.05)

Variable	**p-value**	**P800/3** **EP800/3**	**P800/4** **EP800/7**	**P1000/3** **EP1000/3**	**P1000/4** **EP1000/4**	**P1250/3** **EP1250/3**	**P1250/4** **EP1250/4**	**Stat. significance**
Y_1	p-value	1.10^{-13}	7.10^{-12}	4.10^{-15}	2.10^{-14}	4.10^{-15}	2.10^{-16}	**Stat. significant**
Y_2	p-value	0.083	0.392	0.239	0.699	0.069	0.070	Stat. insignificant
Y_3	p-value	2.10^{-8}	5.10^{-8}	2.10^{-8}	3.10^{-8}	2.10^{-8}	2.10^{-8}	**Stat. significant**

Table 11. Results of Testing III – strength (α=0.05)

Variable	p-value	P800/3 P1000/3 P1250/3	P800/4 P1000/4 P1250/4	EP800/3 EP1000/3 EP1250/3	EP800/4 EP1000/4 EP1250/4	Stat. significance
$\mathbf{Y_1}$	p-value	1.10^{-3}	2.10^{-8}	4.10^{-5}	3.10^{-2}	**Stat. significant**
$\mathbf{Y_2}$	p-value	4.10^{-51}	2.10^{-42}	7.10^{-46}	2.10^{-37}	**Stat. significant**
$\mathbf{Y_3}$	p-value	1.10^{-6}	2.10^{-6}	3.10^{-5}	2.10^{-3}	**Stat. significant**

variable Y_3 (ductility). On the other hand, it seems that the carcass type has no statistically significant effect, under the given conditions, on the output variable Y_2 (tensile strength).

The ANOVA method (for variables Y_1 and Y_2) and the Kruskal-Wallis test (for variable Y_3) confirmed that renovated conveyor belt strength has a statistically significant effect on all output variables (Table 11).

5. Conclusion

Experimental measurements conducted in laboratory conditions provided the information on tensile properties (relative elongation, tensile strength, and ductility) of selected types of worn conveyor belts with the renovated top cover. Based on the results obtained applying the methods of statistical induction it is possible to assume that the measured values are comparable to the reference values obtained with new, unused conveyor belts with the same carcass type.

Within the research, the output variables (relative elongation, tensile strength, and ductility) were used to compare tensile properties of renovated polyamide and polyamide-polyester fabric conveyor belts. The investigated renovated conveyor belts were of various strengths, as determined by their manufacturers, and various numbers of fabric plies. The comparison was carried out using three input variables (carcass type, belt strength, and the number of fabric plies in a belt) and their effects on three output variables (relative elongation, tensile strength, and ductility).

Tensile properties of renovated conveyor belts were compared applying three different methods and all of them brought the same results.

The conclusions made applying the DOE method, regression analysis, and statistical induction method were as follows:

- The resulting values of relative elongation (Y_1) are affected by the strength of a composite, the number of fabric plies in a composite, and the carcass type.
- The resulting values of tensile strength (Y_2) are affected by the strength of a composite and the number of fabric plies in a composite.
- The resulting values of ductility (Y_3) are affected by the strength of a composite and the carcass type.

Based on all the observed results it may be stated that the carcass type (polyamide or polyamide-polyester) has a statistically significant effect on the resulting values of tensile properties of renovated conveyor belts only for relative elongation and ductility. The type of a composite has no statistically significant effect on the resulting values of the third examined mechanical property of conveyor belts, i.e., the tensile strength.

The analysis of the research described herein indicates that the renovation of the top cover layer of conveyor belts preserves, to a considerable extent, tensile properties of conveyor belts. This information may be helpful for belt users when making decisions on the replacement or renovation of worn conveyor belts.

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