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To cite this article: Miroslaw Bajda *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **95** 042053

Accelerated Comparative Fatigue Strength Testing of Belt Adhesive Joints

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Abstract. Belt joints are the weakest link in the serial structure that creates an endless loop of spliced belt segments. This affects not only the lower strength of adhesive joints of textile belts in comparison to vulcanized splices, but also the replacement of traditional glues to more ecological but with other strength parameters. This is reflected in the lowered durability of adhesive joints, which in underground coal mines is nearly twice shorter than the operating time of belts. Vulcanized splices require high precision in performance, they need long time to achieve cross-linking of the friction mixture and, above all, they require specialized equipment (vulcanization press) which is not readily available and often takes much time to be delivered down, which means reduced mining output or even downtime. All this reduces the reliability and durability of adhesive joints. In addition, due to the consolidation on the Polish coal market, mines are joined into large economic units serviced by a smaller number of processing plants. The consequence is to extend the transport routes downstream and increase reliability requirements. The greater number of conveyors in the chain reduces reliability of supply and increases production losses. With high fixed costs of underground mines, the reduction in mining output is reflected in the increase in unit costs, and this at low coal prices on the market can mean substantial losses for mines. The paper describes the comparative study of fatigue strength of shortened samples of adhesive joints conducted to compare many different variants of joints (various adhesives and materials). Shortened samples were exposed to accelerated fatigue in the usually long-lasting dynamic studies, allowing more variants to be tested at the same time. High correlation between the results obtained for shortened (100 mm) and traditional full-length (3x250 mm) samples renders accelerated tests possible. **Keywords**: conveyor belt, adhesive joints, fatigue strength, belt joints reliability

1. Introduction – the role of splices in ensuring continuous operation of belt conveyors and uninterrupted production

Belt conveyors are commonly used in the transportation of bulk materials, as their main advantages include reliability, relatively low operating cost and high mass capacities. The popularity of conveyor belts in various branches of industry and the global tendency to lower transportation costs create the demand for new, improved and energy-efficient solutions in belt conveyors. Users of belt conveyors expect highly efficient solutions. Research in this field includes idlers with reduced rotational resistance [1], energy-saving belts, and highly efficient power transmission systems [2]. Numerous optimization works are conducted to identify those operating factors and design parameters [3] which minimize the power demand of belt conveyor drive mechanism. All these factors influence the costs of transportation with conveyor belts and the durability of the transportation system, i.e. the structural components of the belt conveyor and the conveyor belt itself.

Belt conveyors are commonly used in underground mining. An underground copper ore mine operates over 100 km of belts with almost 800 splices (mean section length is approx. 140 meters). Half of the splices remained in operation for the time shorter than 26 months and 10% – for more than 70 months. Current mean operating time of splices is approx. 33 months (the median is 25 months). The standard deviation of the current operating time for splices is 31 months. Since the mean operating time of a disassembled splice is approx. 60 months, each year the mine replaces about 20% of splices. Most of splice replacement procedures are performed during planned downtime. Some splices are replaced along with belt section replacements, and the rest are replaced preventively, to ensure that the weakened splices do not break when conveyor is in operation. Emergency downtime is related to significant production losses and therefore splice reliability and high durability are of great importance for the continuous operation of the transportation system and for the maintenance of low transportation costs [4].

2. Splicing methods and the role of adhesive joints

The types of splices used in underground mines include adhesive, vulcanized and mechanical joints. Adhesive joint method (“cold” vulcanization) and proper vulcanization method (heat curing) are used to splice multiply textile belts. Performing such type of splices is time-consuming, but they ensure high strength of the splice. Textile rubber belts are cold spliced using two-component glue. With time, molecules in such glue undergo cross linking. This process is equivalent to vulcanization and hence it is frequently referred to as cold vulcanization. Adhesive joints are used in all types of textile belts, irrespective of their width [5]. Prior to splicing, belt ends need some adequate preparation. The rubber cover and the individual plies are torn along the length of each step. The rubber layer between the plies is roughed delicately so that the ply fabric is not damaged – for instance using a wire brush. In the next step, after an adequate quantity of adhesive and curing agent has been prepared, splice surface is glued. This action is usually repeated twice or three times (at adequate time intervals). The upper and the bottom half of the splice are carefully assembled and then roller finished. This last step is necessary in order to press out gas pockets, which occur in the adhesive joint. It also ensures better adhesion between the spliced belts. Fig. **1** shows a diagram of 4-ply belt splice

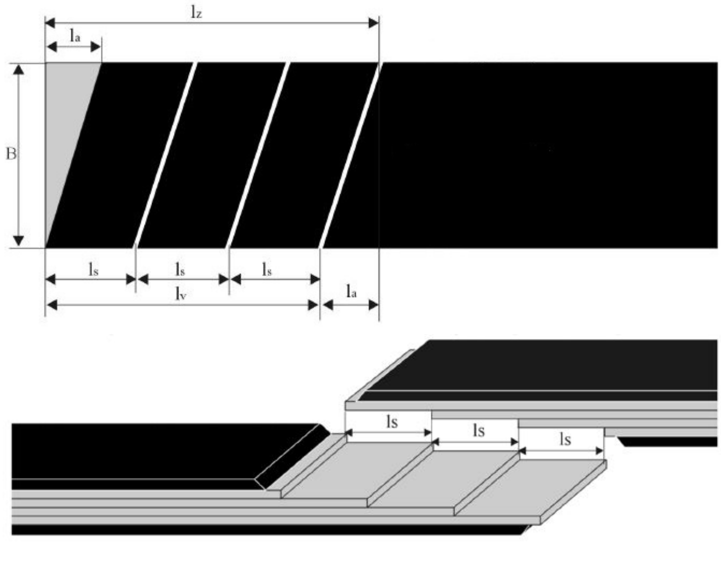

Figure 1. Position of mark-out lines on a 4-ply belt and the method of preparing the belt for splicing (according [6]), l_z – belt length required to perform the splice; l_a – bevel length; l_s – step length; l_v – splice length; B – belt width

Adhesive joint technology is considered the most proper method of splicing. It has a number of advantages, as well as some disadvantages. Adhesive joints allow the continuity of the belt, are strong and durable. They interact well with idlers and pulleys on a belt conveyor. Their major disadvantage, however, is low rupture strength as compared to the rupture strength of the belt. Such splices frequently break without any apparent symptoms [7]. The quality of the splice depends on the condition of the belt ends to be connected, on the materials used and also, largely, on the experience and diligence of technicians who design and prepare the splice [7]. Vulcanized splices are used in all types of belts. Heat vulcanization is performed in vulcanizing presses. These presses must provide proper pressure and temperature and must be approved for use in underground mines. In the case of textile belts, splicing requires several hours but normally does not exceed 12 hours – this time depends on belt thickness [6]. Vulcanization of rubber belts is performed at the temperature of approx. 145^0 C. Although the procedure is time-consuming and requires expensive, heavy and bulky equipment, it has a number of advantages. Splices of this type have the highest mechanical strength properties and the highest durability. Limited sensitivity to external factors (inter alia thermal and moisture sensitivity) is also of some importance. Mechanical splices are yet another type of connections. Two types of mechanical splices are distinguished: separable and non-separable. They are typically constructed using inter alia single and double hooks, and hinged connections such as clamp, coupling or other. Separable joints allow disconnecting the belt ends by removing the connection cord. In non-separable connections, the belt ends are permanently fixed to each other. Mechanical splices are performed in belts having low or average rupture strength. They are frequently used in the case of conveyors which must be shortened, lengthened or moved from place to place. As compared to adhesive or vulcanized joints, mechanical joints have significantly limited durability. Therefore, this type of connection is considered an emergency joint for stronger belts. Metal elements located on belt cover have an adverse effect on idler coats, as well as on rubber parts of cleaning devices and on pulley lining. Moreover, a splice of this type exposes belt core to water and thus facilitates the delamination of plies.

3. Description of research into the fatigue strength of splices carried out at the LTT laboratory

The object of research as part of the current financial grant [13] covers cold adhesion joints in multiply belts and the chemically hardening glues used to make such splices.

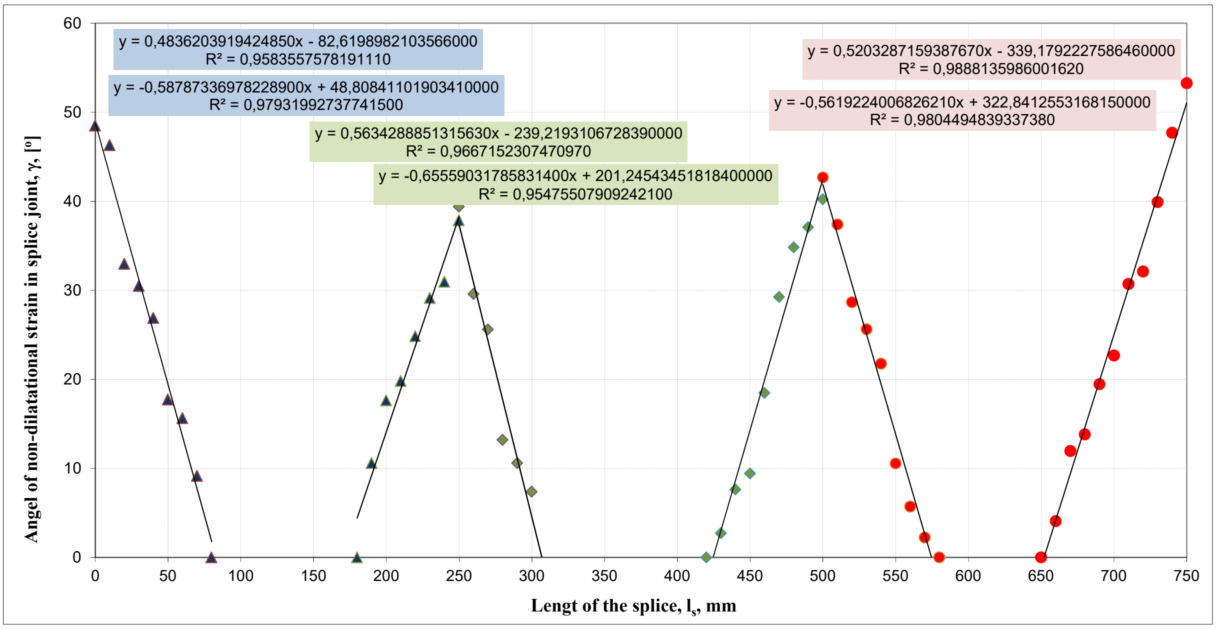

Figure 2. Angles of non-dilatational strain in splice joint γ along the length of the splice

The fatigue life of splices was tested using four-ply samples of a 750 mm long splice (3 steps, each of 250 mm in length). Cyclic loading had the frequency of 0.3 Hz and the following sinusoidal pattern [12]: for minimum load B = ¾· R_r ·b ·0.05 N/mm, for maximum load B = ¾· R_r ·b ·0.02 N/mm where:

R_r – actual belt tensile strength, in N/mm

b – the width of the measurement part of the sample, in mm.

The tests performed as part of the tasks listed in the project's schedule covered stress in the adhesive material of the splice and the fatigue of sample splices. The tests of strain in the adhesive joints were performed on four-ply belts having nominal strengths of 800, 1000, 1400 and 1600 kN/m. The test was performed according to the following procedure: the sample of a joint made with chemically hardening glues was properly prepared and placed in the jaws of the testing machine; in the next step, it was loaded with a force which caused the stress in the belt to exceed the belt's actual strength by 20%; the final step consisted in measuring the non-dilatational strain in the adhesive joint.

The results for the sample splice have been presented in the graphs, as a function of splice length (Figure 2). The obtained measurement results were then smoothened, since approximation with mathematical equations was needed to transform angles γ into joint unit elongation ε. The measurement points were approximated using such formulas that the correlation coefficient R^2 was close to one. The transformation of angles γ into strain ε was achieved using the relationship: $\varepsilon = (1 - cos\gamma)/cos\gamma$. The results of these calculations for the sample splice are shown in Fig. 3.

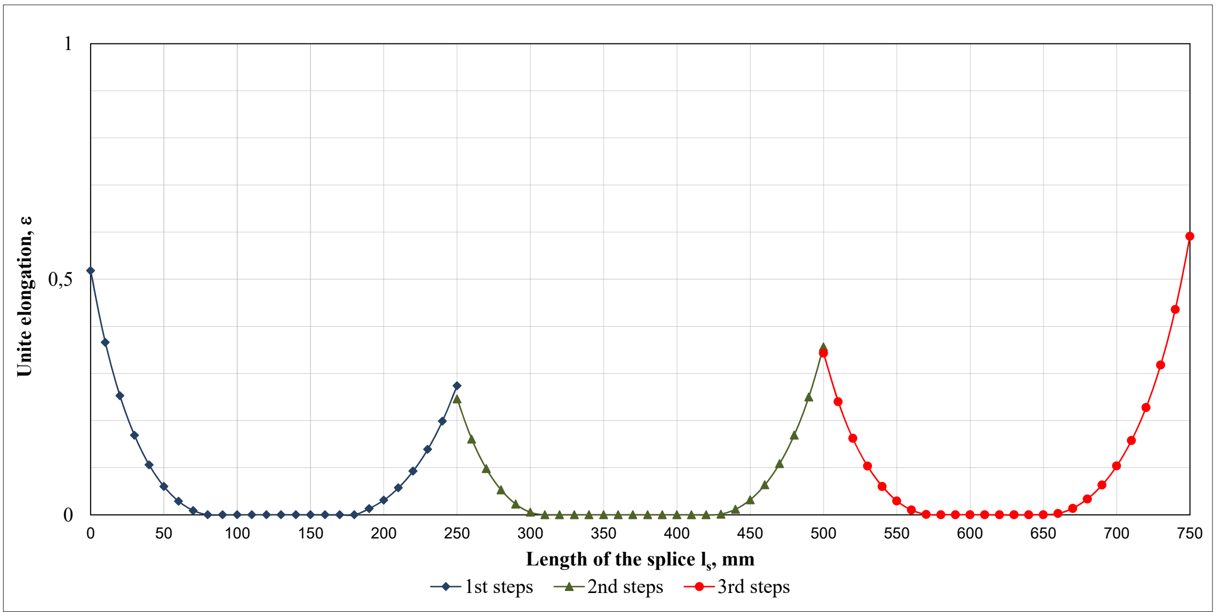

Figure 3. Adhesive joint unit elongation ε along the length of splice

Creating a stress pattern for the adhesive joint along the length of the splice required the investigation of dry remnants of chemically hardening glues so as to identify the relationship between stress and elongation $\delta = f(\varepsilon)$. Further calculations allowed a graphical representation of stress values in the adhesive joint as a function of splice length (Figure 4).

A more precise analysis of the results required additional calculations and providing information on the following values: inclination angle of the graph regarding axis x (Figure 2), step length utilization factor, stress concentration factor and joint loading coefficient [13]. The research results so far indicate that stress in the joint shows maximum values at the beginning and at the end of the length of each step, while in the middle area, it has a minimum that is close or even equal to zero. This leads to a question about the effectiveness of step length and of the whole splice. The currently used splice

IOP Conf. Series: Earth and Environmental Science **95** (2017) 042053 doi:10.1088/1755-1315/95/4/042053

lengths were standardized in PN-C-94147:1997 [12], in which they remain dependent on ply strength. Due to recent significant progress in the quality of the currently produced belts and belt splicing materials, the lengths of splice steps approved in the above standard may need verification. Such verification may only be based on tests which would allow for multiple factors that affect strength and fatigue life. Some of these factors are the object of research performed as part of the grant [13].

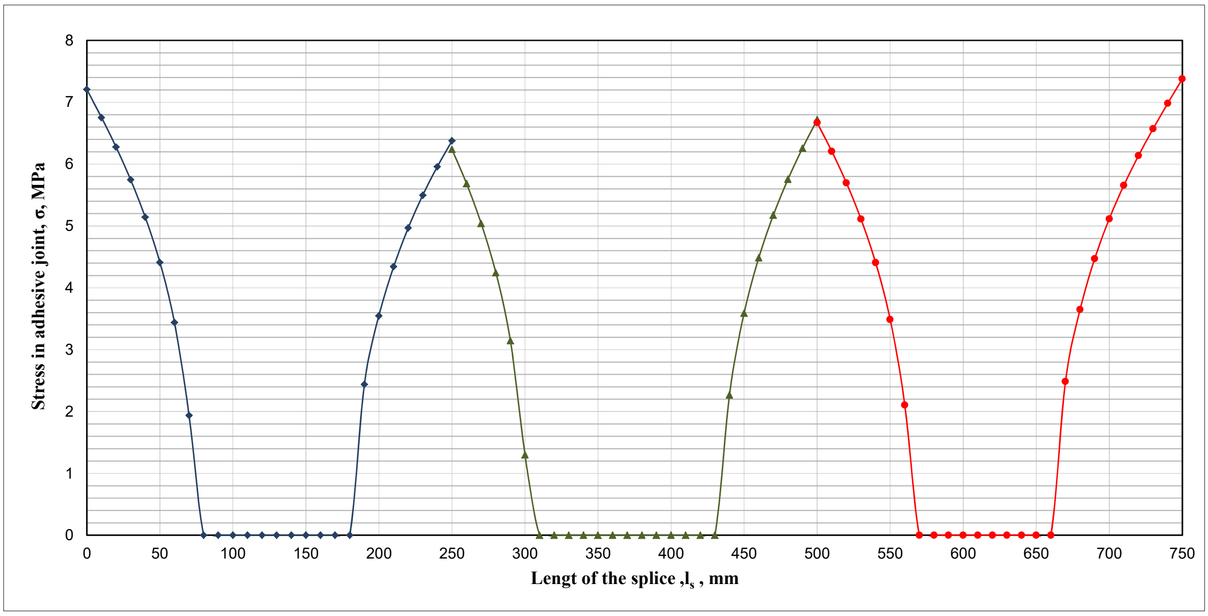

Figure 4. Stress in adhesive joint σ along splice length

4. Accelerated tests of splice fatigue strength

Fatigue strength tests performed as part of this research program remained in accordance with the methodology developed at Wroclaw University of Science and Technology [8, 9, 10, 11]. The methodology for accelerated splice strength tests uses static and dynamic loads and requires easily available equipment and small sized samples. Shear stress in the layer between the plies is considered to be a reliable measure. Therefore, fatigue strength is described as the number of loading cycles which the sample is subjected to before it is damaged. The dimensions of the tested samples are shown in Fig. 5. Sample width is 30 mm, its total length – 500 mm, while the length of the section subjected to shearing is 100 mm. These are optimal dimensions selected on the basis of pilot tests. Samples of various shapes and dimensions were tested. In order to generate shearing stress, the first two plies needed to be cut on both sides of the tested sample.

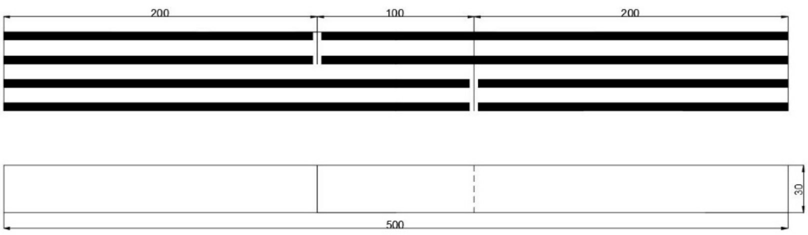

Figure 5. Sample provided for fatigue tests (schematic view – at the bottom, longitudinal section with visible plies – at the top)

Prior to tests, the edges of each of the samples were sprayed with a thin layer of paint to facilitate the observation of the fatigue in the adhesive joint. In the next stet, the tested sample was placed in the jaws of the Zwick Roell Amsler HC 25 servohydraulic machine (Fig. 6). The sample was subjected to

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cyclical loading and unloading with 0.3 Hz frequency and within the range of forces which correspond to 5% and 20% of the belt's actual strength. Since the tested splice had one step, the minimum load was calculated in accordance with the standard [12], from relationship 1, and the maximum load was calculated from relationship 2.

$$F_1 = 0.25 \cdot R_r \cdot b \cdot 0.035\ [N] \quad (1)$$

$$F_2 = 0.25 \cdot R_r \cdot b \cdot 0.35\ [N] \quad (2)$$

where:
F_1 – minimum load, in N,
R_r – actual belt strength, in N/m,
b – width of the fatigue strength test sample, in m.

During the tests, the machine was connected to a computer equipped with appropriate software that allowed recording the force, the elongation, the measurement time and the number of cycles until the sample ruptured. The measured parameters allow the tracking and the analysis of the changes which occur during the test of a single sample (the change in the hysteresis loop of the load on the sample) [9]. Fig. 6 shows the sample of a 100 mm long single step splice for accelerated fatigue tests, during the test on a pulsator.

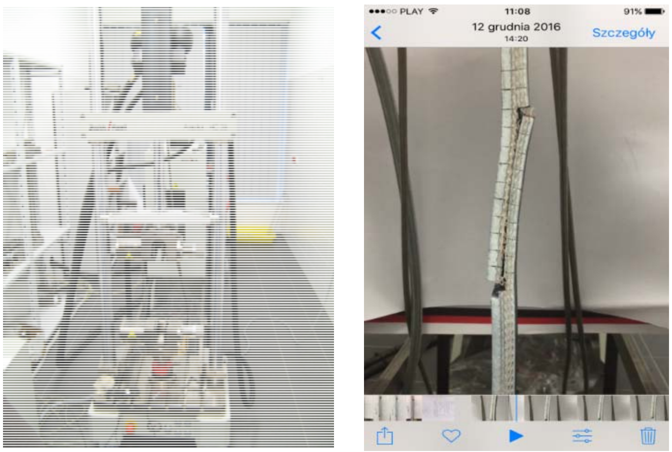

Figure 6. The Zwick Roell Amsler HC 25 machine for fatigue tests (on the left) and a sample during the test (on the right)

-1.0 1.0

	R_bs	Q_j2b	R_del	Tal	BS_a	El_ba	M_j	M_100j	M_ar	Nc_j	Nc_100j
R_bs		1.00	-0.97	-0.85	0.78	-0.90	-0.50	0.15	0.40	-0.80	0.68
Q_j2b	1.00		-0.97	-0.85	0.78	-0.90	-0.49	0.16	0.41	-0.80	0.68
R_del	-0.97	-0.97		0.70	-0.91	0.77	0.27	-0.38	-0.61	0.92	-0.84
Tal	-0.85	-0.85	0.70		-0.33	0.99	0.88	0.39	0.14	0.36	-0.19
BS_a	0.78	0.78	-0.91	-0.33		-0.43	0.16	0.74	0.89	-1.00	0.99
El_ba	-0.90	-0.90	0.77	0.99	-0.43		0.82	0.29	0.03	0.46	-0.30
M_j	-0.50	-0.49	0.27	0.88	0.16	0.82		0.78	0.60	-0.13	0.30
M_100j	0.15	0.16	-0.38	0.39	0.74	0.29	0.78		0.97	-0.71	0.83
M_ar	0.40	0.41	-0.61	0.14	0.89	0.03	0.60	0.97		-0.87	0.94
Nc_j	-0.80	-0.80	0.92	0.36	-1.00	0.46	-0.13	-0.71	-0.87		-0.98
Nc_100j	0.68	0.68	-0.84	-0.19	0.99	-0.30	0.30	0.83	0.94	-0.98	

R_bs - belt strength, kN / m
Q_j2b - quotient of joint strength to belt strength, %
R_del - delamination strength of the joint, kN / m
Tal - shear strength, kN / m2
BS_a - breaking strength of adhesive, kN / m2
El_ba - elongation at break of adhesive, %
M_j - full-length joint module
M_100j - 100 mm joint module, kN / m2
M_ar - adhesive rubber module, kN / m2
Nc_j - number of full-length joint cycles
Nc_100j - number of 100mm joint cycles

Figure 7. Pearson Product Moment Correlation

The splices were prepared so as to investigate the stress in the adhesive joint and also to observe stress in the friction rubber layer above and below the adhesive joint. This provides means to verify the results of tests performed on full-length splices (3x250 mm).

The initial results from the tests were subjected to statistical multivariable analysis. The investigations covered more than ten strength parameters of a 4-ply conveyor belt type EP 1000 and its adhesive joints (both full-length ones and those shortened to 100 mm) made with 3 different types of glue. Strength parameters of the rubber and of the glues were also investigated. The Pearson Product Moment Correlation between the investigated parameters was graphically represented in Fig. 7. Its analysis revealed many interesting relationships of varying strength, which enable the construction of predictive models based on the parameters of the belt, the rubber and the glue. The correlation of the number of fatigue cycles for samples cut from full-size splices and from shortened splices with multiple parameters allows a more extensive analysis, since not only the test time shortens (fatigue occurs at a smaller number of cycles) but also the same amount of material can provide more samples.

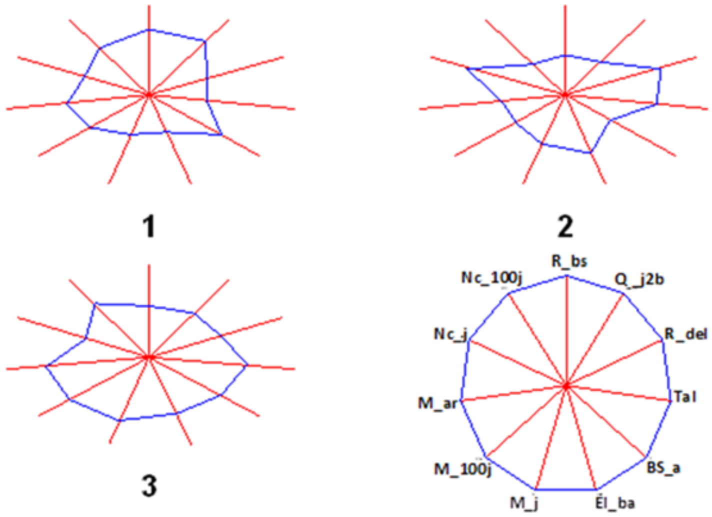

Figure 8. Radial graph of the glyphs representing the diversification of the parameters of 3 splices

The representation of the parameters in the form of glyphs (Fig. 8) shows how diversified are the analyzed splices. At this stage, the collected data are insufficient to build a regression model for many variables. However, some strong relationships between particular parameter pairs exist, for instance shear strength (Tal) in the function of elongation at break of adhesive (El_ba), or the relationship between the number of cycles in a fatigue test and the delamination strength of the joint R_del (Fig. 9).

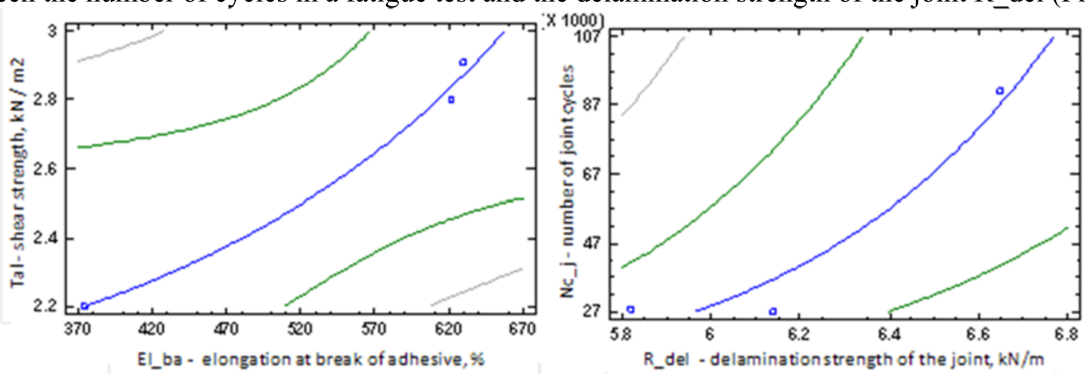

Figure 9. Exemplary regression diagrams for strongly correlated pairs of parameters

Research into such relationships is ongoing and will be continued. A plan exists to select multivariable regression models which will allow the prediction of the practical properties of a splice, based on strength parameters of the belt, the friction rubber and glues, so as to find optimal parameters for splices and splicing materials.

5. Conclusions

In Poland, mining industry alone uses approx. 1 000 km of belt conveyors. This translates into approx. 2 000 km of conveyor belts in operation. Since the length of belt sections varies from 100 m to 300 m, the number of splices can be roughly estimated at approx. 10 000. Almost 800 of them are in operation in oe of the underground mines. Their durability is varied and depends on a splicing technology and operating conditions. Open cast lignite mines mostly operate steel-cord conveyor belts, which are spliced with vulcanized joints. Such splices provide relatively high durability, comparable with the durability of the belt. The durability of adhesive joints in underground hard coal mines is lower than the durability of the belt, and hence a risk exists that the continuous operation of transportation systems will be interrupted, causing substantial production losses. In American mines, the financial loss caused by 1 minute of emergency downtime is estimated at 1000 USD, and this means that an emergency downtime to reconstruct the broken splice may cost the mine as much as 250 000 USD (a minimum of 4 hours to remove the bulk material and to splice the belt). Therefore, much effort should be put to investigating the reasons behind reduced durability of adhesive joints, which are frequently used in Polish underground mines. Such research is also expected to provide guidelines on how to optimally select splicing materials (the composition of friction rubber and glues) so as to maximize the fatigue life of a splice.

This paper describes the research methodology for fatigue strength tests of conveyor belts, developed and used in the LTT laboratory at Wroclaw University of Science and Technology to investigate full length splices on textile belts [8, 9]. Since such tests are expensive and long, this paper also offers accelerated tests for splices shortened to 100 mm, performed by applying cyclical dynamic load exceeding the stress which occurs in the belt when normally operated. The paper also presents the results of preliminary research [13]. These results are insufficient to build models, but they point to strong correlations between the investigated parameters, which may be used to build such models in the future.

Acknowledgment(s)

This publication was financed from the funds of a project carried out under the Applied Research Programme in path A, titled “Zlacza wieloprzekladkowych tasm przenosnikowych o zwiększonej trwalosci eksploatacyjnej” (Joints of multi-ply conveyor belts with increased functional durability) No. PBS3/A2/17/2015.

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[13] Research grant No PBS3/A2/17/2015 titled: Joints of multi-ply conveyor belts with increased functional durability (Zlacza wieloprzekladkowych tasm przenosnikowych o zwiekszonej trwałosci eksploatacyjnej) - financed from the funds of a project carried out under the Applied Research Programme in path A.