OPTIMIZING SPLICE GEOMETRY IN MULTIPLY CONVEYOR BELTS| WITH RESPECT TO STRESS IN ADHESIVE BONDS

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Abstract: This paper presents the results of investigations into stress distribution in the adhesive bonds of multiply conveyor belt splices. The splices were cold-vulcanized with the use of chemically hardening glues having various strength parameters. The research results demonstrated that the length of splices may be reduced without the risk of lowering their tensile strength and fatigue life. The paper presents stress values in adhesive joints of various belt types and the influence that the properties of belts, splices and splicing materials have on stress values in the adhesive bond of the splice.

Keywords: *belt conveyor*, *conveyor belt*, *textile belt splices*, *splice testing*

1. INTRODUCTION

Increasing importance of belt conveyor transportation systems is accompanied by increased expectations regarding their reliability. A need exists to design new, efficient and economically justified solutions for belt transportation. This goal may be achieved in the first place by lowering main motion resistances of the belt conveyor, i.e. lowering fictive friction coefficient f (Gładysiewicz et al. 2017). Greatest energy consumption reductions may result from adequate idler selection (Król et al. 2017), from optimal spacing of load bearing idler sets (Gładysiewicz et al. 2016), and in

some cases also from unconventional solutions used in the design of routes, take-up arrangements and transfer devices (Kawalec & Kulinowski 2007).

Energy efficiency and proper operation of a belt conveyor is largely influenced by the properties of the belt installed on the conveyor (Gładysiewicz & Konieczna 2016; Hou & Meng 2008). The belt serves to hold and move the transported material along the conveyor. It also carries longitudinal forces required to overcome motion resistances when the conveyor is not equipped with a separate driving belt. The belt must have an adequate longitudinal and transverse strength to safely carry the loads which occur when the material is dropped from the transfer device and transported over an idler set. The belt must also carry loads transferred from the conveyor drive mechanism via the pulleys. At the same time, the belt should be sufficiently elastic to properly adjust to the shape of the trough and enable the application of pulleys with optimal diameters (Żur & Hardygóra 1996).

Conveyor belts are manufactured in segments having 100 m, 200 m, or 300 m in length, depending on belt weight and on the accessibility of the destination site. Depending on the length of a belt conveyor, it may have a small or a great number of splices. The splices are made not only when a new belt is installed but also when its individual segments are replaced due to wear, damage or the need to shorten or lengthen the conveyor route (Żur & Hardygóra 1996). Splicing procedures are performed throughout the life of the conveyor. The splicing procedure results in the discontinuation of the belt structure and consequently in reduced belt strength in the location of the splice. The splice is therefore the weakest part of the belt loop (Kirjanów 2015; Kozłowski 2015). Thus, splice strength has a decisive influence on the reliable operation of a belt conveyor (Błażej et al. 2015; 2016).

Multiply textile belts are the oldest type of conveyor belts and have been used for over 100 years (Hardygóra et al. 1999). The splice in such a belt is a layer-based structure with a complex distribution of stress due to disturbed belt structure, which results from discontinuing the textile plies in the belt core. This type of conveyor belts is most commonly used in underground mines.

According to the current, and increasing, standards in the reliability and durability of transportation systems, belt splices should demonstrate high strength and life. A splicing procedure is a multi-stage task performed typically on site, on the conveyor and in difficult mining conditions. The cost of such a splicing procedure is high, as it covers the value of both the materials and the labor and as the conveyor is taken offline for a long period (U.S. Department of Energy 2004). As a result, the production is decreased or even completely stopped, if the mine operates a single transportation line. Thus, the speed and quality of splicing procedures significantly influence the costs of mining operations.

However, as the splice strength has so far remained lower than the belt strength, the parameters of spliced belts prevent them from being used to the limit (Bajda et al. 2017). Therefore, current research focuses on detailed analysis of the phenomena ob-

served in the splice region, as their better understanding will allow optimized splice geometry and increased splice strength and durability (Project NCBiR 2015).

2. RESEARCH METHODOLOGY

Previous research into the strength of splices in textile belts served to determine the key factors influencing static tensile strength of splices (Komander et al. 2011). Practical operation of conveyor belts leads to an observation that their splices become delaminated in the regions of their outer contacts. This phenomenon is a proof that due to fatigue loads the adhesive bond is more subject to damage than the covers. Increasing the fatigue life of an adhesive bond is thus important for increasing splice durability. The above fact motivated research aimed at finding which properties of conveyor belts and their splicing materials have the most significant influence on stress levels in the adhesive bonds of cold-vulcanized splices. The research methodology was developed as part of a research project carried out at Laboratorium Transportu Taśmowego (Belt Conveying Laboratory), Wrocław University of Science and Technology (Project NCBiR 2015).

2.1. TESTS OF STRESSES IN ADHESIVE BONDS OF SPLICES

The object of tests consisted of three-step splices in four-ply textile belts, which were made in accordance with the scheme shown in Fig. 1. The splicing technology is of great significance to strength parameters of splices. The quality of such operations as stepping of the plies and removing their friction rubber, as well as vulcanization conditions, may result in defects which lower splice strength. Therefore, in order to eliminate the possibility of error, the surfaces of splices were meticulously prepared in controlled conditions in an aboveground laboratory.
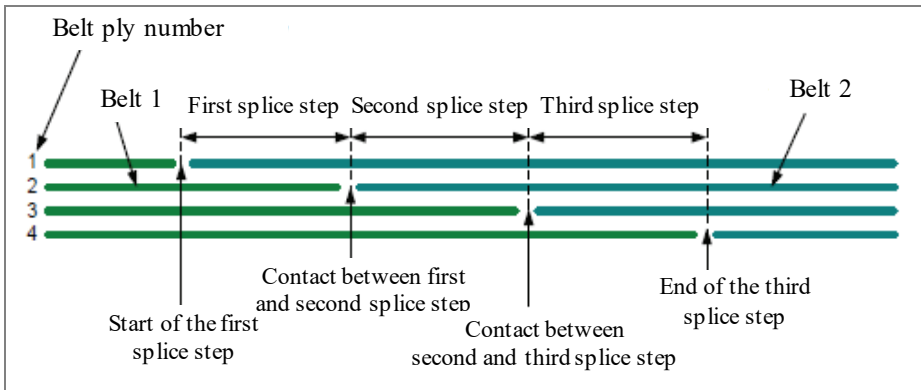

Fig. 1. Scheme of a three-step splice in a four-ply belt

The stress-measurement method consists in measuring the non-dilatational strain angle of the adhesive bond in splices subjected to cyclical tensile loads, and in subsequently calculating the results into stresses (Hardygóra et al. 2012). Angle γ is defined as the quotient of bond strain ΔS and the distance between the shifting plies (Fig. 2).
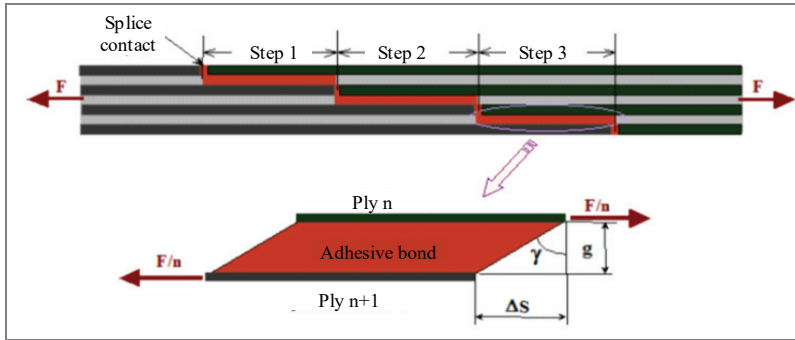

Fig. 2. Samples for testing stress in adhesive bond (Hardygora et al. 2012)

Dynamic tests of splices having lengths 750 mm, 700 mm, 600 mm and 550 mm were performed on a testing machine. The lengths of individual steps in the splices are provided in Table 1. The dynamic tests were performed with the following test parameters assumed:

1. During the tests, the temperature of the adhesive bond was ensured not to exceed the normal temperature, i.e. 23 ± 2 °C. For this reason the tests were performed in an air-conditioned room, at a constant temperature of 19÷21 °C. The temperature condition is of significance for rubber tests, as rubber strength properties largely depend on temperature. The temperature of the adhesive bond was controlled with the use of a thermal vision camera.
2. The tensile loads were selected on the basis of safety factors presented in the DIN 22101 standard. DIN 22101 as of 2011 contains safety factors to consider operating conditions. However, different loading scenarios are not discussed in it. The documented loading conditions of belt conveyors are described in the work of Geesmann (Geesmann 2001) and Katterfeld (Katterfeld et al. 2016).

During typical operation on the conveyor, the belt is subjected to loads corresponding to 5% of its strength. Conveyor operates in predefined conditions, for example at sub-capacity loading with material. For nominal loads (belt maximally filled with material), the maximum force in the belt is assumed (depending on belt type) on the order of 10÷15% of its tensile strength. 20% load may be assumed the limit load in extreme conditions or on very long conveyors (several kilometers in length). During the tests here described, 5% loads were assumed as working loads, while 20% loads – as maximum loads in extreme working conditions (e.g. starting the operation of a level or inclined conveyor loaded with material in winter).

3. The frequency of splice tensioning was set at 0.3 Hz. At higher frequency the temperature of the adhesive bond increases above 25 °C.

The tests of strain in the adhesive bonds were performed on the splices of four-ply belts having nominal strengths of 800 and 1000 kN/m. The test were performed according to the following procedure: the splice sample (Fig. 2) made with chemically hardening glues was placed in the jaws of the testing machine cyclically (0.3 Hz) loaded with a force which effected stresses in the belt at between 5% and 20% of its actual strength. After 3000 loading cycles, non-dilatational strain in the adhesive bond was measured. In order to find the strain in the bond, the splice sample required proper preparation. For that purpose, the edge of the sample was carefully cleared, prepared and sprayed with a thin paint coating. A specially designed contour template was used to mark vertical lines on the side of the sample. After 3000 loading cycles, the deformed splice was photographed. Figure 4 shows a fragment of the splice sample with deformations of the adhesive joint at the end of the third splice step, which is located between the third and the fourth ply. The damage visible in the bottom left part of the photograph is the end of the splice (see Fig. 1). Defects in this location are typically the most extensive. The photographs were subsequently processed with the use of the computer and the results served to plot a graph of non-dilatational strain angle of the adhesive bond versus splice length. Each photograph of a vertical line was analyzed separately. It was zoomed as required and processed in specialist software in order to read precise values of non-dilatational angle in the adhesive bond. Figure 3 shows sample readings of the non-dilatational strain angle of the adhesive bond versus splice length.
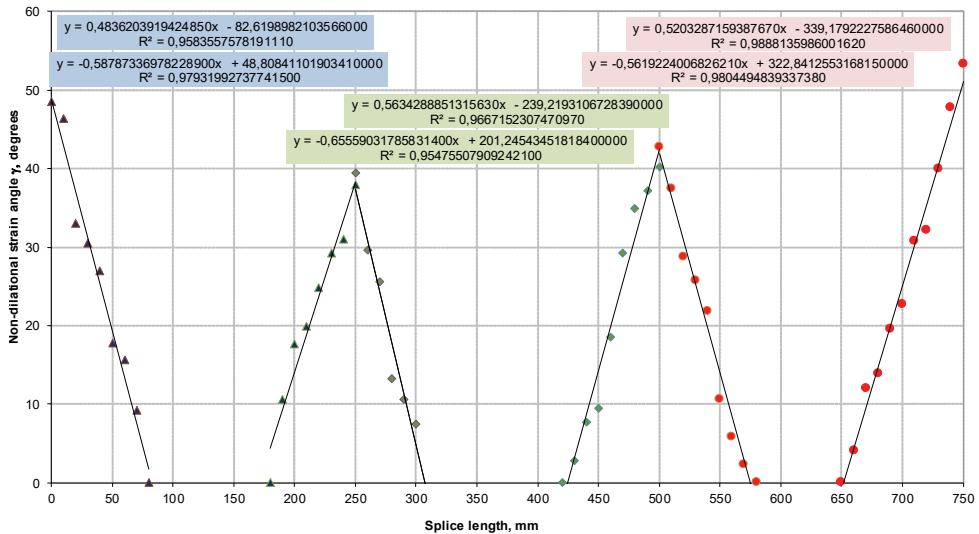

Fig. 3. Non-dilatational strain angle of the adhesive bond in the EP 1000/4 belt (Project NCBiR, 2015)

The outer contacts of the splice showed significant bond strain exceeding 50°. The deformations lower quickly towards the central part of the step, where a region is observed in which angle $\gamma = 0$ (l_0). Non-dilatational strain angles on the contacts of inner steps are smaller than on the contacts of outer steps, and the length of the zero-deformation zone l_0 of the inner step is greater than in the case of the outer steps.
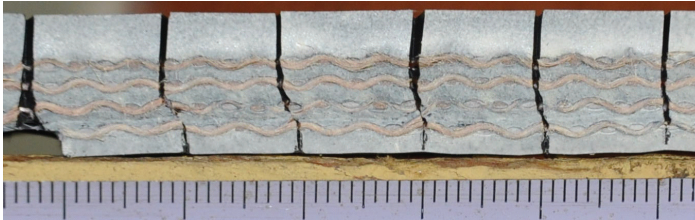

Fig. 4. Example of deformations in the adhesive bond of the splice
located at the end of the third step, between ply 3 and 4

Further, the procedure consisted in calculating the values of angles γ into unit elongations of the adhesive bond. By calculating the angles into elongations and by allowing for the characteristic values of rubber adhesive tensioning, it was possible to plot graphs of stress distribution in the adhesive bond along the length of particular splice steps. Their examples are provided in Fig. 5.
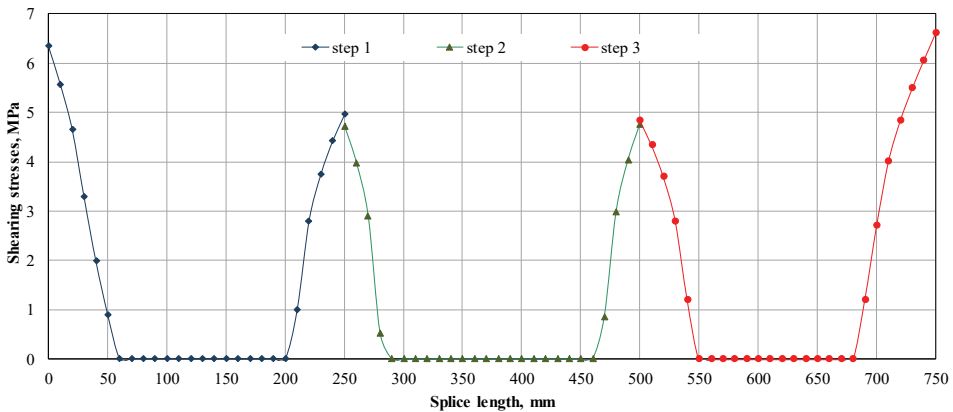

Fig. 5. Example of stress distributions in the adhesive bonds of a splice

The measurements included the values of non-dilatational strain angles γ in the adhesive bonds of various three-step splices 750 mm (3×250 mm) in length. The results indicate that with the splice loaded with a tensile load equal to 20% of belt strength,

angles γ in the central fragments of adhesive bonds for each step are equal to zero. This fact means that these regions are not subjected to shear stresses. The length l_0 of these fragments is a reserve indicating that the splice length may be reduced to some extent. This observation applies in particular to the inner step, as the stresses on its contacts are lower than the stresses on the contacts of the outer steps.

2.2. TEST RESULTS

Test results of stresses acting on the contacts of splice steps having shortened geometry are provided in Table 1. Splices marked 1÷4 are made of belt having actual strength equal to 793 kN/m, while splices marked 4÷8 are made of belt having actual strength equal to 1097 kN/m.

Apart from splices having a standard length of 750 mm (Nos. 1 and 5), Table 1 also includes test results for splices having various step lengths:

- splices 2 and 6 – inner step length reduced by 50 mm, outer step lengths unchanged, splice length equal to 700 mm,
- splices 3 and 7 – all steps have lengths reduced by 50 mm, splice length equal to 600 mm,
- splices 4 and 8 – inner step lengths reduced by 50 mm, middle step length reduced by 100 mm, splice length equal to 550 mm.

Table 1. Maximum stresses acting on the contacts of splice steps

Splice No.	Splice step length l_s, mm			Splice length L_p, mm	Length of the $\gamma = 0$ regions in the splice l_0, mm	Max. shearing stress on step contacts, σ_{max}, N/mm^2
	1	2	3			
1	250	250	250	750	373	7.3
2	250	200	250	700	343	7.7
3	200	200	200	600	301	8.4
4	200	150	200	550	291	9.2
5	250	250	250	750	390	7.2
6	250	200	250	700	366	7.7
7	200	200	200	600	299	8.2
8	200	150	200	550	279	9.1

The research project also included investigations into stresses in splices made with the use of four-ply belts having actual strengths from 800 kN/m to 1600 kN/m. The belts for splicing, as well as the splices themselves, were tested in order to find their basic strength properties (Project NCBiR 2015).

3. TEST RESULTS ANALYSIS

The research demonstrated that the greatest values l_0 occur in splices having length equal to 750 mm. Reducing the step length results in reduced lengths of segments l_0 and thus – reduced area of the regions which do not carry loads. At the same time, maximum stresses on step contacts increase. Figure 6 shows how these stresses increase in relation to shortening the splice.
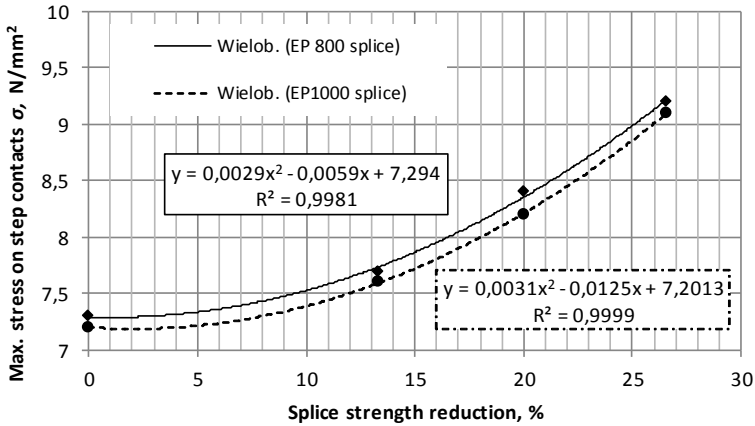

Fig. 6. Relationship between max. stresses on step contacts
and the extent of step length reduction

The research into the relationship between individual splice step lengths and stresses in the adhesive bond demonstrated that shortening the inner step by 50 mm had practically no influence on the stress values. Reducing the length of all steps by 50 mm, and hence of the whole splice by 20%, effected an increase of stress by approx. 14%. At the same time, segments l_0 were shortened, leading to more effective usage of the steps.

The research into the relationship between individual splice step lengths and stresses in the adhesive bond demonstrated that shortening all steps by 50 mm had no influence on the stress values. Although reducing the length of the inner step by 100 mm slightly increases stresses in the adhesive bond of the inner step, the stress values are still significantly lower than stresses in the outer steps, while step lengths are used more effectively. The influence of splice step length on the values and distributions of stress in adhesive bond are illustrated on the example of a splice made in belt EP-1000/4 and shown in Fig. 6.

The upper graph shows stresses in a typical splice having length $3 \times 250 = 750$ mm. The stress distributions are to a great extent non-uniform: high stresses are observed on the contacts of the outer steps and lower – on the contacts of the inner steps. At the

same time large regions are observed not to take part in the load-carrying process. The middle graph shows the distribution of stresses in the adhesive bond of a splice in which the length of the inner step is reduced to 200 mm, and the bottom graph shows stresses distribution in a splice, in which the outer steps were shortened by 50 mm and the inner step was shortened by 100 mm. The splice shortened by 200 mm in a 200 + 150 + 200 = 550 mm pattern has a more uniform stress distribution. Stresses on the outer contacts are slightly greater than stresses in a standard splice, and the regions which do not carry loads are smaller.
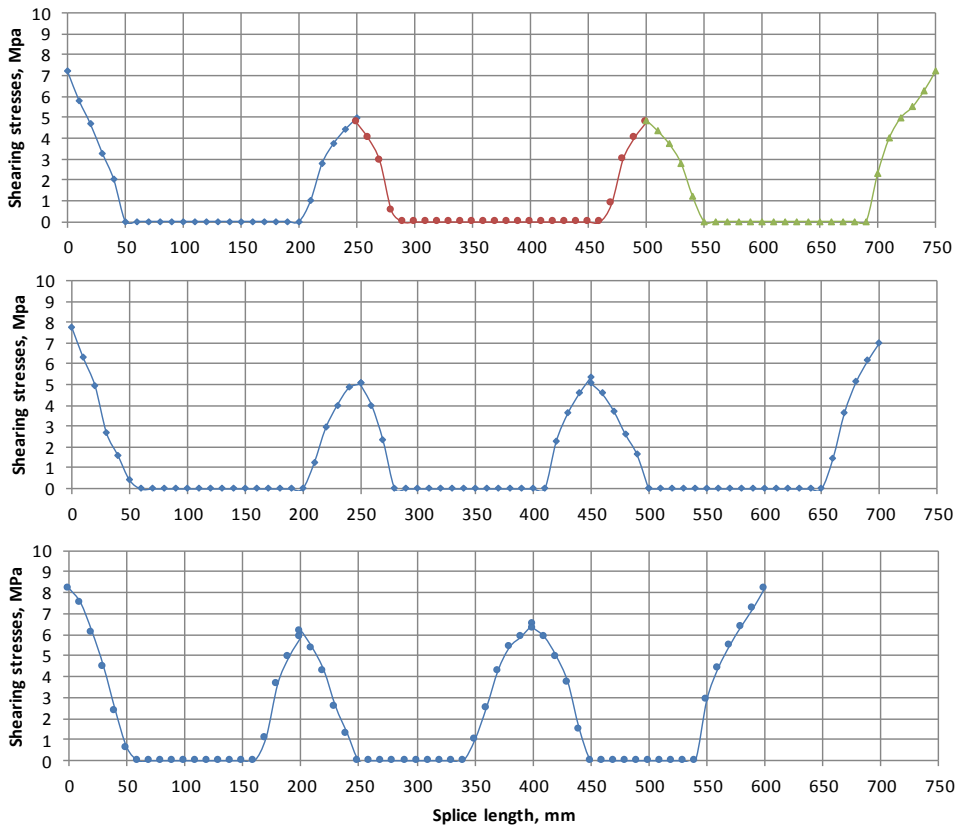

Fig. 6. Stress distribution in the adhesive bond along the length of the complete splice:
upper – 750 (3 × 250) mm, middle – 700 (250 × 200× 250) mm, bottom – 600 (3 × 200) mm

According to PN-C-94147:1997 the lengths of individual steps in a splice are equal and depend on the strength of an individual ply (Table 2).

Based on the research results, a conclusion was made that the length of steps in cold-vulcanized splices may be reduced and that the inner steps in a splice may be shorter than the outer steps without reducing splice strength or durability. The fatigue

tests of shortened splices did not indicate lowered durability in comparison to standard splices (Project NCBiR 2015). The new recommended splice step lengths are provided in Table 2.

Table 2. Splice step lengths

Belt ply strength R_N, kN/m	Splice step length according to PN-C-94147 l_{st}, mm	Recommended step length l_{st}, mm	
		outer	inner
Up to 150	150	100	100
From 160 to 250	250	200	150
From 350 to 400	350	300	200
From 500 to 630	400	350	250

In the case of dimensioning a splice in a 5-ply belt having nominal strength of 2000 kN/m and single ply strength of 400 kN/m, the standard splice length of $4 \times 350 = 1400$ mm was reduced to 1000 mm.

The results of belt and splice tests (Project NCBiR 2015) were analyzed in order to determine how maximum stresses on splice contacts τ depend on the splice modulus M_{splice}, on its delamination strength R_{delam} and on belt shear resistance τ_{belt}. Multiple linear regression with logarithmic transformation allowed selecting a function having correlation coefficient $R^2 = 84.1\%$ and the following form:

$$\tau = 0.640224 \cdot M_{splice}^{-0.639} \cdot \tau_{belt}^{2.95339} \cdot R_{delam}^{-0.197},$$

where:

τ – maximum shearing stresses in the adhesive bond on splice contacts, MPa,
M_{splice} – splice modulus, kN/m^2,
R_{delam} – splice delamination strength, kN/m,
T_{belt} – belt shear strength, kN/m^2.

The results of belt and splice tests demonstrated that high durability of adhesive bonds in cold-vulcanized splices may be obtained by using materials of the following parameters:

- the relationship between belt modulus of elasticity and splice modulus of elasticity should be <1.2,
- the adhesive rubber should have low modulus of elasticity, similar to the modulus of the friction rubber in the spliced belts – below 2 MPa, determined at rubber elongation equal to 100%,
- the adhesive rubber should have high tensile strength, over 14 MPa,
- the adhesion strength of the adhesive rubber to the ply should be high and exceed 6 N/mm.

4. CONCLUSIONS

The research results confirmed high influence of belt and splice strength parameters on the values of stresses in the adhesive bond. The relationship was quantified. The lowest values of stress are obtained when belts have high modulus of elasticity and the splicing materials have low modulus of elasticity.

The results also indicate that the splice lengths currently recommended in industry standards may be reduced. The inner step in a splice may be shortened by as much as 40%. Fatigue tests of splices with reduced lengths of inner steps demonstrated that their shortening does not affect their durability.

The research is continued in cooperation with splice users in order to verify the obtained results in actual operating conditions. If proven accurate, the results may be implemented in practical applications and provide significant savings in belt and in splicing materials, as well as in the splicing time.

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