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Monitoring creep and stress relaxation in splices on multiply textile rubber conveyor belts

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The article discusses one of the most important issues related to a failure-free operation of belt conveyors, i.e. the problem of inspecting belt splices (Andrejiová, 2016; Zimroz et al., 2011), which are the weakest links in a belt loop operated on a conveyor (Jurdziak et al., 2016; Jurdziak, 2000). It presents the results of the investigation into the phenomena of creep and stress relaxation that occur in two different types of heat-vulcanised splices made on multiply textile rubber conveyor belts. The scope of investigation covered measuring the elongation of adhesive joints both in the connection points between individual splice steps and along the full length of the adhesive joint. The measurements of adhesive joint elongation included the allowance for creep and were performed directly after the load was applied to the splice. The findings suggest that although splice deformation is significant, the changes in the stresses that occur in the adhesive joint remain insignificant due to stress relaxation. In practice, a several-hour waiting time should be assumed before measurements can be taken. During operation, splices on multiply textile rubber conveyor belts undergo significant deformation due to material creep. Therefore, most information is provided by investigating splices of standard, full length. This paper presents the results of tests that take this phenomenon into consideration. Such tests have never been performed before, and their results constitute important information for the producers and users of conveyor belts. They allow an optimal choice of adhesive compositions used in splicing multiply textile belts and also they indicate directions for further research.

Key words: *mine transport, textile conveyor belts, conveyor belt splices, belt splices testing, belt core elongation, experiment*

Introduction

In belt conveyor systems, the most costly component to maintain is the conveyor belt (Ambriško et al., 2016; Andrejiová et al., 2015; Bindzár, 2008). Its operation often determines the reliability of the entire system (Król et al., 2015; Król et al., 2016). During operation of the conveyor, the belt is subjected to varying loads (Gładysiewicz et al., 2016; Grinčová, 2014; Molnár et al., 2014; Molnár et al., 2014). It is cyclically loaded and unloaded along the belt conveyor route and unevenly loaded while passing through intermediate section (through a belt to flat belt) and over conveyor drums (Gładysiewicz et al., 2011). The factors mentioned above cause the degradation of the belt which decreases its life time (Błażej, 2003). Additionally, the weakest element in a belt loop is its splice (Mazurkiewicz, 2012).

Conveyor belts are manufactured in sections of 100 m, 200 m, or 300 m in length, depending on belt type, weight and transport capability. The length of a standard belt conveyor is usually several times greater than the length of an individual belt section. Due to the above, the desired belt length is achieved by splicing multiple belt sections into one loop. Several splices must be made on a single belt conveyor. The splices are made on occasions, e.g. when a new belt is installed, when the installed belt becomes worn out and/or damaged and requires replacement, or when conveyor operation necessitates adjusting belt length. In the areas where splices are made, the discontinuity of belt structure reduces belt strength. Hence, splices are the weakest elements of a belt loop. In practice, a large number of splices are prematurely destroyed during belt loop operation. The design of new construction of splices is the aim of the project (2015) which is currently carried out at the Wroclaw University of Science and Technology. Stresses in the adhesive bond in splices, their strength and fatigue life have been determined based on originally developed research method (Błażej, 2003; Hardygóra et al., 2012; Project, 2015). The obtained results will be the basis to define the new requirements regarding the properties of a belt and joining materials.

Properly performed splicing procedure, with splices of appropriate structure, technology and quality, positively affects the strength of the whole belt loop. The most appropriate solution is belt joining with hot vulcanisation methods or cold glueing since it provides the best strength and durability of splices (Ziller, 2010). Splice strength has several characteristics (Hardygóra et al., 2015; Ziller, 2010). Most information is provided by determining ultimate tensile strength for full-scale splices (Hardygóra et al., 2015). During operation, splices in textile-rubber belts are subjected to significant strain due to material creep (Findley, 1989) and hence this phenomenon should be considered when belt tests are performed.

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Material and Methods

The strength and durability of splices in rubber-textile conveyor belts pose a constant challenge to the users of such belts. Some belt splices show limited fatigue life due to incorrect splicing procedures. Even correctly performed splices may be prone to premature wear or separation. The strength and fatigue life of splices strongly depends on selecting the best adhesive material for the given type of conveyor belt. This issue is currently researched in the Laboratorium Transportu Taśmowego (Belt Conveying Laboratory, further: LTT) at Wroclaw University of Science and Technology. The investigations cover the influence of the properties of plies and rubber mixtures on the strength of full-scale splices as well as fatigue tests on laboratory test pieces (Hardygóra et al., 2015; Project`, 2015). A large number of factors that affect the results of tests, especially the results of fatigue tests, causes problems in obtaining repeatable results. Also, such tests require a significant number of samples to be analysed in identical conditions (including the temperature of samples). This paper presents the results of tests, during which the test pieces had the temperature of 23±2 °C.

Conveyor belt splices typically have multiple steps, and the stresses that occur in individual plies on the first belt are transferred to plies on the second belt via an adhesive joint layer. Fig. 1 shows an exemplary 4-ply splice.

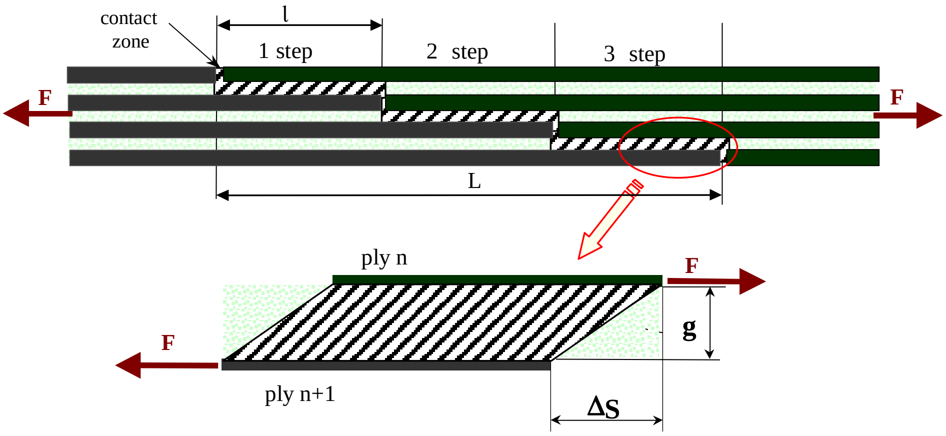

Fig. 1. Example of a 4-ply splice.

Average shearing stresses τ_m that occur in the adhesive joint as a result of force F, equal to:

$$\tau_m = F/(b \cdot L) \qquad (1)$$

where:

F – tensile force acting on belt, expressed in [N]
b – belt width, in [mm]
L – splice length, in [mm]

are not distributed uniformly along the whole splice length. This phenomenon results from the elastic properties of both the material used in the plies and the adhesive joint, as well as from the splice structure. The analysis of strain and stress in the adhesive joint cannot be based on the relationship (2) because this relationship applies only to materials in which stress is directly proportional to strain.

$$\tau = \gamma G \qquad (2)$$

where:

γ – angle of non-dilatational strain, in [°]
G – modulus of non-dilatational strain, in [N/mm^2]

The assumed method of measuring stress in adhesive joints is based on measuring the angle of non-dilatational strain in the joint γ and finding unit elongation ε from the geometric model of strain in the joint's element, as shown in Fig. 2.

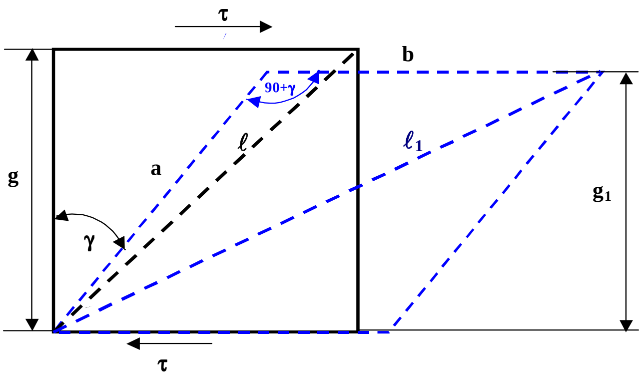

Fig. 2. Geometric model of strain in the joint's element.

According to this model, unit elongation of any of the joint's elements ε is described by the relationship:

$$\varepsilon = \sqrt{\frac{(\varepsilon_k+1)^2+(\varepsilon_t+1)^2+2(\varepsilon_k+1)(\varepsilon_t+1)\sin\gamma}{2}}-1 \tag{3}$$

where:

$$\varepsilon_k = \frac{1-\cos\gamma-\varepsilon_t\nu}{\cos\gamma+\nu\sin\gamma}$$

ε_t – belt unit elongation, in [%]
ν – Poisson ratio for rubber, [dimensionless]

In the above equation, coefficient ν is a value dependent on rubber unit elongation ε. The ν=f(ε) relationship is established experimentally. Belt unit elongation ε_t depends on the belt's stress value at which stress distribution in the joint is determined. It is expressed as the l_x, function, i.e. as the function of location along the joint and is the result of splice construction, in which individual plies have discontinuity spots. Along the step, stress distribution in the belt has values between $\sigma_{śr}$ and σ_{max}, and variation in the range between $\sigma_{śr}$ and σ_{max} has sinusoidal distribution (Fig. 3).

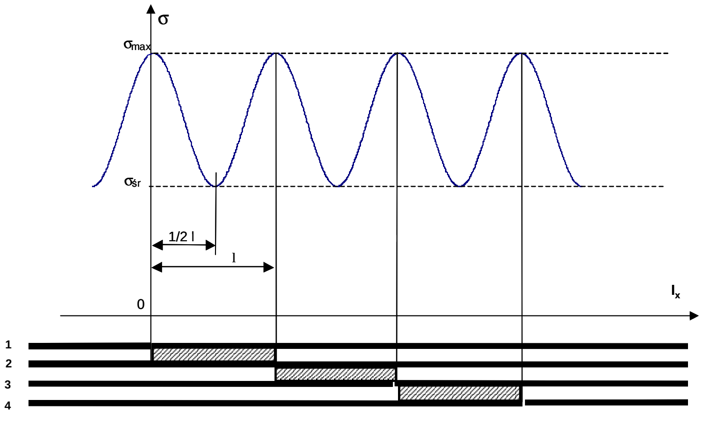

Fig. 3. Stress distribution in conveyor belt plies along the splice.

Maximum stress values in the belt occur at step contacts and are:

$$\sigma_{\max} = \frac{z}{(z-1)k}\sigma_{śr} \tag{4}$$

where:

z – number of plies in the belt
k – stress concentration ratio in plies at step contacts, [dimensionless]
σ_m = F/b – stress in the belt outside the splice area, in [N/mm]

Normally, the $\sigma_{śr}$ stress also occurs mid length particular steps, where shear stresses in the adhesive joint are close or equal to zero. Stress in plies along the l_x length of the step may be calculated using the relationship:

$$\sigma_t = \frac{\sigma_{\max} - \sigma_{śr}}{2}\left(\cos\frac{2\pi}{l} l_x + 1\right) + \sigma_{śr} \tag{5}$$

Based on belt tensile characteristics, σt values are assigned to unit elongation values εt and this allows to establish the εt=f(lx) relationship.

Angles of rubber non-dilatational strain γ are measured at selected points along the adhesive joint using special indicators situated in the joint. The position of the indicators is recorded with a video camera before and after the splice is subjected to force F (Ambriško et al., 2016). The results of the measurements allow obtaining the dependence of angles γ from lx and, after appropriate calculations are performed, to prepare a diagram of the distribution of adhesive joint elongation along the splice ε=f(lx). The image of stress distribution in the adhesive joint along the splice is obtained by performing rubber tests, which serve to establish the relationship between stress and elongation σ=f(ε). This allows translating the previously obtained elongation values into stress values σ=f(lx).

Results and Discussion

Creep is the tendency of a solid material to deform under the influence of prolonged stress. Tensile force F subjects the belt splice to stress, which takes individual values in individual points. Hence, due to creep, individual splice elements undergo various forms of strain. Whether the strain causes a change in the distribution of stress in the splice, as compared to stress measured directly after subjecting the splice to tensile forces, becomes the next question for investigation. The above-described method served to perform research that allowed to prepare diagrams $\sigma=f(l_x)$ for stresses which occurred in the adhesive joint after tensile force F was applied first for a short and then for a long time. The main goal of this research was to compare the obtained stress distributions.

The tests allowed to measure the following strength characteristics:

- the tension in conveyor belt splice,
- the tension in rubber adhesive joint,
- creep in the conveyor belt and
- creep in belt splice.

Tension characteristics for the belt and rubber were measured according to adequate national and European standards. Tests of creep were performed by applying certain tensile forces to the samples and measuring their unit elongation at set time intervals. The tests were performed within 100-hour time range. The obtained creep curves may be extrapolated (Andrejiová et al., 2015) in order to establish elongation ε_T after load time T of any length, based on the formula:

$$\varepsilon_T = \varepsilon_0 \left(\frac{T}{b}\right)^m \tag{6}$$

where:

ε_T – unit elongation, in [%]
ε_0 – instantaneous strain, in [%]
b, m – constants that characterise the material
T – load time, in [hours]

Constants b and m may be calculated from several creep test results. Conveyor belt creep tests were performed on the EP1000/4 belt, using a test stand shown in Fig. 4.

Fig. 4. Stand for testing conveyor belt splices.

Sample dimensions were as follows:

- length – 3000 mm
- width – 200 mm

A 2000 mm long measurement basis was marked on the samples. The samples were fastened in the jaws of the testing machine and subjected to tensile force F=30 kN, which results in tensile stress $\sigma_{śr}$=F/b=30/0.2=150 kN/m (15 % of the belt's nominal strength). The selection of loads was based on safety factors as per DIN 22101. A load corresponding to 5 % of belt strength occurs in operating conditions typical for a conveyor belt. Conveyor's operating conditions are predefined, and they include for instance incomplete loading of the conveyor with bulk material. Depending on the type of belt, for nominal loads (maximum loading of the belt with the bulk material) the maximum strength in the belt is assumed at 10 – 15 % of the belt's breaking strength.

Other samples of the same belt were subjected to stress:

$$\sigma_{\max} = \frac{z}{(z-1)k}\sigma_{śr} = \frac{4}{(4-1)0{,}85}150 = 235\ [kN/m] \qquad (7)$$

The results of the tests are shown in Tables 1 and 2 as well as in Fig. 5.

Tab. 1. Results of creep tests on the EP1000/4 belt at $\sigma_{śr}$=150 kN/m stress.

Load time T in hours	0.01	0.5	1.5	3.5	6.5	11	27	50	80	100
Unit elongation ε_t, [%]	2.25	2.6	2.7	2.8	2.85	2.9	3	3.1	3.17	3.2

Tab. 2. Results of creep tests on the EP1000/4 belt at σ_{max}=235 kN/m stress.

Load time T in hours	0.01	0.5	1	3	6	29	53	77	100
Unit elongation ε_t, [%]	3.05	4.01	4.18	4.42	4.56	4.83	5.01	5.09	5.19

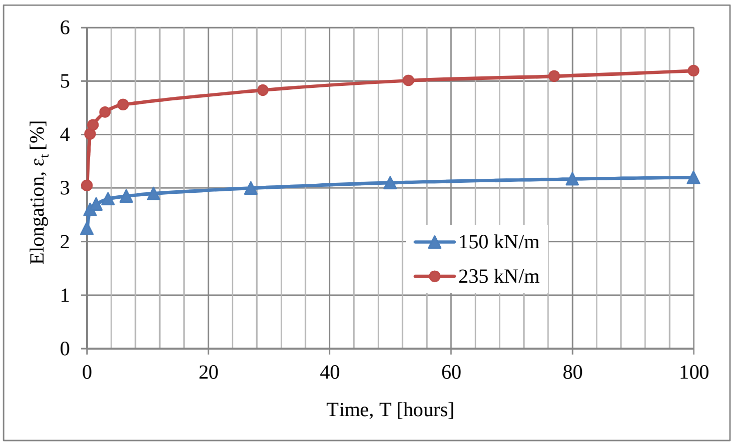

Fig. 5. Diagrams of creep in the EP1000/4 belt.

The test results served to prepare diagrams shown in Fig. 6, which allow finding ε_t values for any σ_t values within a range between $\sigma_{śr}$ and σ_{max}.

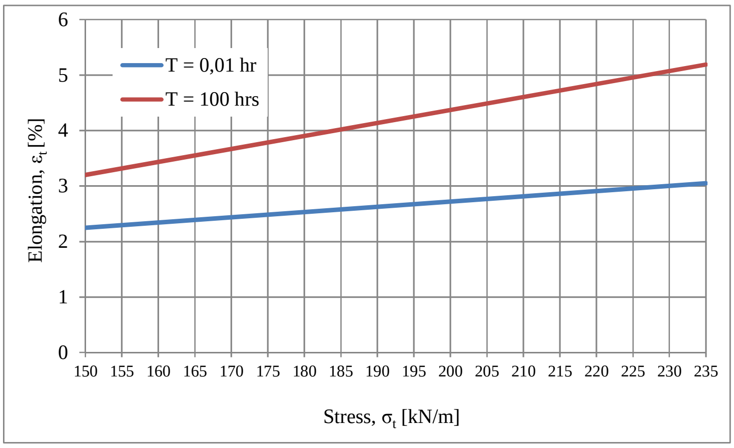

Fig. 6. The relationship between belt elongation ε_t and stress σ_t.

Rubber creep tests were performed on two types of concoctions marked with symbols ANX and FPN. Each rubber type served to prepare 7 samples measuring 2x15x330 mm. A 200 mm long measurement basis was marked on the samples. Each sample was loaded with weights of increasing mass. Fig. 7 shows the test stand.

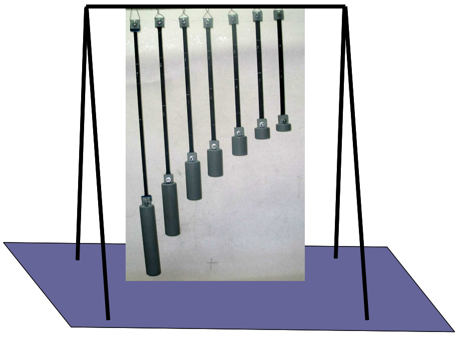

Fig. 7. Test stand for measuring creep in rubber samples.

The measurement results are shown in Figs. 8 and 9.

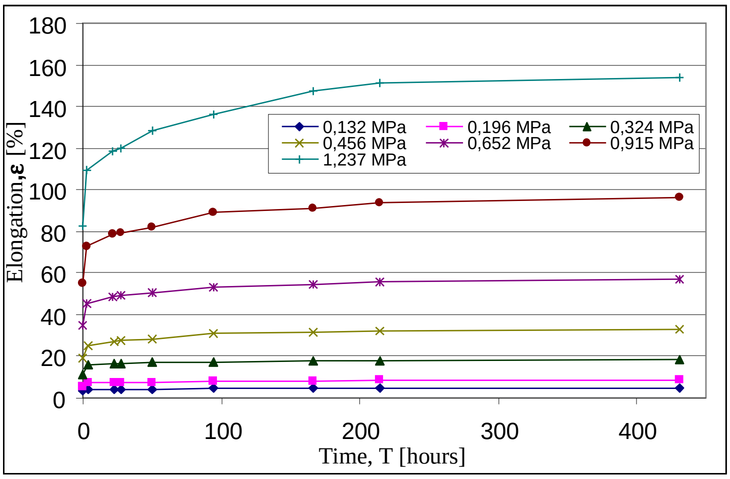

Fig. 8. Creep test results for FPN rubber.

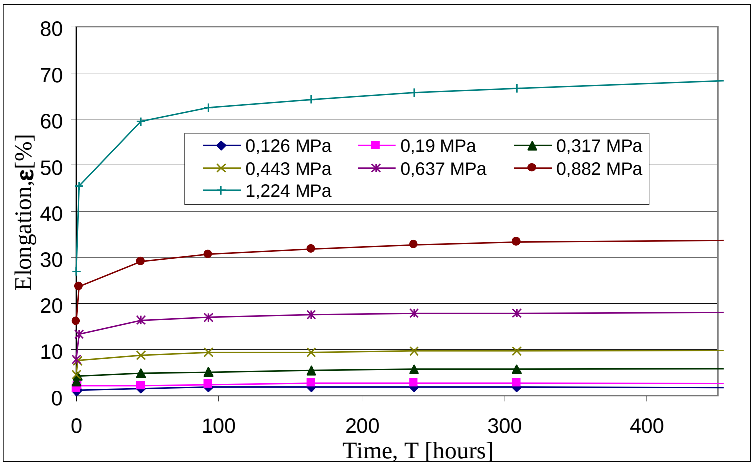

Fig. 9. Creep test results for ANX rubber.

Table 3 as well as Figs. 10 and 11 show the relationship between rubber elongation ε and tensile stress σ for time T=0.01 hr and T=100 hrs (Andrejiová, 2016).

Tab. 3. Creep test results for FPN rubber and ANX rubber.

Sample No.	**FPN rubber**			**ANX rubber**		
	Stress σ [MPa]	**Elongation ε** [%]		**Stress σ** [MPa]	**Elongation ε** [%]	
		T=0.01 hr	T=100 hrs		T=0.01 hr	T=100 hrs
1	0.132	2.75	4.52	0.126	1	1.75
2	0.196	5	7.77	0.19	1.25	2.58
3	0.324	11	17.3	0.317	3	5.27
4	0.456	18.75	31.1	0.443	6.5	9.25
5	0.652	35	53.2	0.637	8.5	17
6	0.915	55	89.1	0.882	15	30.8
7	1.237	82.5	137	1.224	26.5	62.7
8	1.56	90	-	1.31	36	-
9	1.89	117.5	-	1.8	47	-
10	2.14	140	-	2.04	60	-

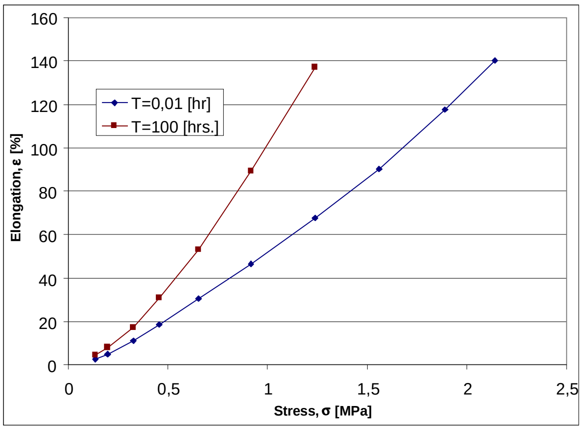

Fig. 10. Dependence of FPN rubber elongation ε on stress value σ and on time T.

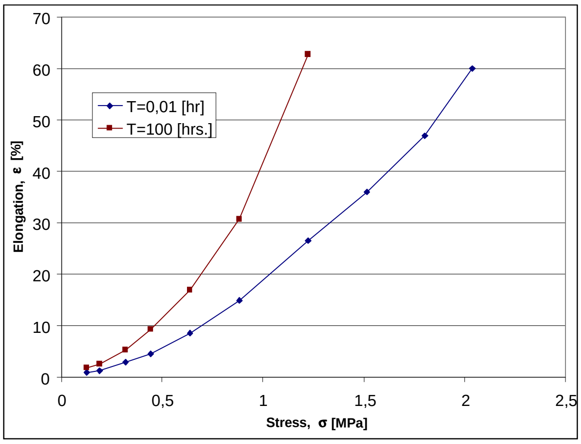

Fig. 11. Dependence of ANX rubber elongation ε on stress value σ and on time T.

Tests for creep in belt splices were performed on two types of splices: EP-FPN and EP-ANX. The splices were made with full dimensions, as per PN-C-94167:1997. Splice step length was l=250 mm, total splice length was L=3x250=750 mm, bevel 0.3xB (B – belt width). Each of the splices served to provide two test samples 200 mm in width for stress distribution in adhesive joint and two samples to measure the shear strength and delamination strength. The 200 mm splice samples were fixed in the jaws of the testing machine and subjected to tension with force F=30 kN, which corresponds to 15 % of the belt's nominal strength. Such load served to measure angles of non-dilatational strain in the splice joint γ (at 15 mm distances) immediately after F force was reached (after time T=0.01 hr) and after time T=100 hrs. Fig. 12 shows the measurement results for one of the outermost splice steps.

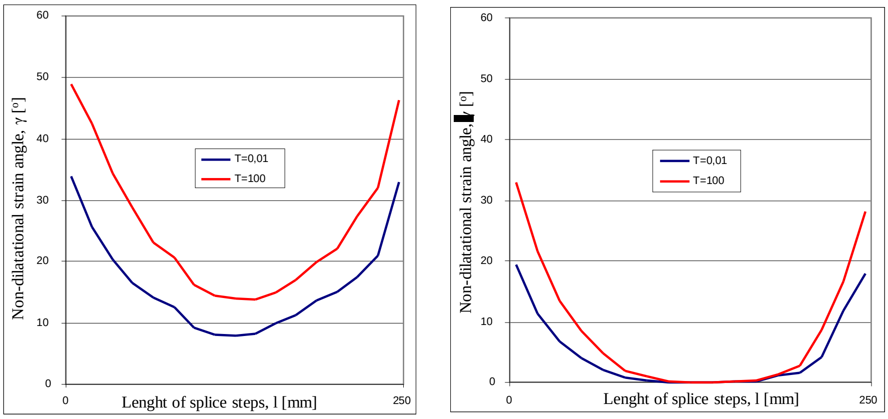

Fig. 12. Distribution of non-dilatational strain angle γ along the splice step.

The results of adequate calculations are shown in two figures. Fig. 13 shows the distribution of adhesive joint elongation ε values along the splice step and Fig. 14 shows the joint tensile stress σ distribution along the splice step.

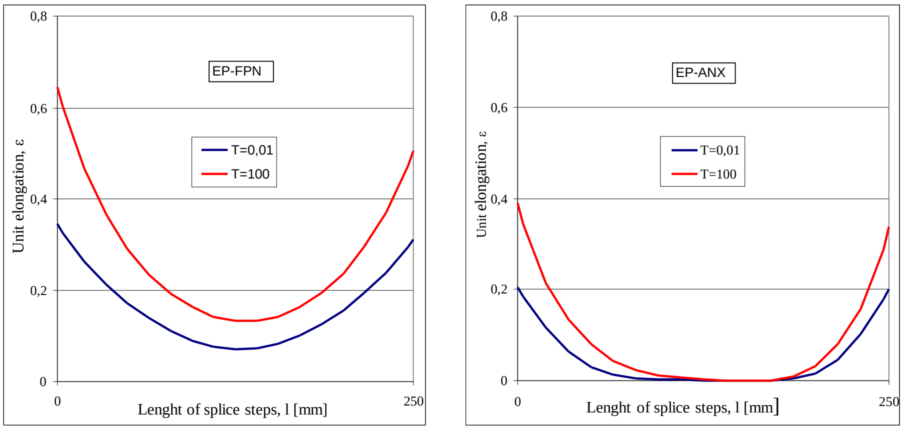

Fig. 13. Distribution of elongation ε along the splice step.

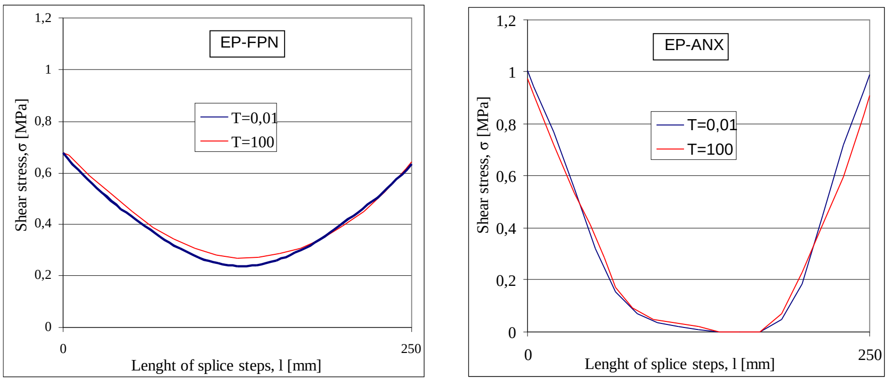

Fig. 14. Distribution of shear stress σ along the splice step.

The analysis of graphs shown in Figs. 13 and 14 suggest that both mean elongation and mean stress in the adhesive joint are significantly lower than for the ANX composition. In the case of stress values on the contact points of the splice step, the ANX mixture has 30 % higher stress as compared to stress in the splice performed with the FPN adhesive mixture. In the middle area of the splice, however, the shearing stress has a value close to 0. This fact suggests a possibility to reduce the length of the splice, i.e. to change its geometry. Practically, this can positively influence the time and cost splicing procedures.

Current research at LTT covers the optimisation of step lengths in multiply belt splices, which will take into account other additional parameters of belts and adhesive mixtures, as well as splicing technologies.

Conclusions

The research into the influence of relaxation on the level of stress in the adhesive joint, as described in this paper, shows that despite significant strain in the adhesive joint, the stress in the joint along the splice demonstrates only minimal change. Hence, the investigated splices do not need to be subjected to long-lasting loads. Additionally, new information was obtained by the test method that guarantees more accuracy. The information suggests that the tests should be optimally performed after the load has been applied for several hours, most advantageously for 3 or 4 hours since the tensile load was applied to splices. After such time, joint elongation occurs at a very slow pace.

Belt splices subjected to long-lasting tensile loads are prone to significant deformation, due to which the adhesive joint elongates in contact areas by about 200 % as compared to instantaneous elongation recorded immediately after the splice is loaded. At the same time an observation has been made that despite significant strain, stress in adhesive joint remains minimally altered, due to the phenomenon of stress relaxation.

The EP-FPN splice is characterised by a more advantageous, more uniform stress distribution along the joint, as compared to the EP-ANX splice. Stress values in the contact areas of the first splice are also about 30 % smaller than in the second splice.

The obtained results allow concluding that performing stress tests in the splice joint is not necessary after application of long-lasting load. In order to avoid significant measurement errors, the tests should not be performed immediately after applying the load to the splice, as the elongation increases in the unit of time faster in the initial period of stress. In practice, a several-hour waiting time should be assumed before measurements can be taken.

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