1. Introduction

Multiplies conveyor belts manufactured in parts of certain length are connected into longer sections or loops according to the pattern showed on figure 1.

The specificity of splice construction is that in cross-sections of plies contacts is one ply less than in belts being connected. Loss of belt strength in the splice area is inversely proportional to the number of belt plies.

Test results of static strength of splices indicate that loss of strength is bigger than the one resulting from the loss of one ply. This is caused by shearing stresses in the adhesive joint, which are the biggest on the ply connections and strengthen the function of notch at that point of splice. During the test of static tension of properly manufactured splice it is destroyed due to breakage of plies on the joint of the first or the last notch. Often in practical use the connections of splice are unstuck, what is the beginning of its destruction. It results from the fact that under the fatigue loads the adhesive joint is damaged [1,2,3].

Problems related with establishing what properties of conveyor belts and vulcanization materials have the essential impact on the stresses in the adhesive joint and its fatigue life, were the subject of studies carried out in Laboratory of Belt Transportation of Mining Laboratory at Wroclaw University of Technology [4,5]. The results are presented in the paper.

2. Tests of stresses in adhesive joint of conveyor belt splice.

The size of stresses in adhesive joint of splice was tested by measuring the angle of non-dilatational strain of γ joint. γ angle is defined as ratio of absolute ΔS non-dilatational strain and the distance between relocating edges of the joint under the F stretch force (fig.1).

\[ \tan \gamma = \frac{\Delta S}{g} \]

In view of properties of fabric plies and the rubber of adhesive joint, the angle of γ non-dilatational strain is not the same at the whole length of separate notch of the slice. (fig.2), thus
its measurement must be made at many points along the length of the splice.

**Fig. 2 Strain diagram of the adhesive joint along the length of the 1st step of a belt splice**

The measurements of γ angles were made on the full-scale splices of four-ply belts. To render the test results independent from the impact of possible production defects, the splices were made in the special manner. Individual notches were obtained through cutting the belt plies at certain places equal the notch length.

50 mm wide samples for tests were cut out along the belt axis and then were loaded by the force giving the stress accounting for 15% of belt strength. Basing on measured γ angles, the chart of the γ=f(lx) relation where lx is a distance between the measuring point and the place of contact of cut plies was plotted. Example results of γ measurements after the approximation by the trend line are presented on figure 3.

**Fig. 3 Distribution of non-dilatational strain angles γ in adhesive joint along the length of EP1000/4 and PP1000/4 belt splices**

The charts of γ=f(lx) relations were approximated by trend lines and the relative elongations of ε joint were calculated using the formula (2):

\[
\varepsilon = \frac{1 - \cos \gamma - \varepsilon_t \cdot \cos \gamma + \nu \cdot \sin \gamma}{\cos \gamma + \nu \cdot \sin \gamma}
\]

(2)

where:

- \(\varepsilon_t\) – relative elongation of belt at the stress of 15% of belt strength,
- \(\nu\) - Poisson’s ratio of adhesive rubber.

The foregoing relation was determined investigating the schema of adhesive joint deformation presented on figure 4, assuming that relative elongation of the joint is \(\varepsilon=(g_1-g)/g\) and taking into consideration the impact of belt elongation as well as Poisson’s ratio of adhesive rubber.

The calculations gave the charts of distribution of adhesive joint elongations along the splice length i.e. ε=f(lx). In order to obtain the picture of stresses distribution in the adhesive joint along the splice, the tests of adhesive rubber were carried out to get the τ=f(ε) relation, what in turn helped to recalculate the results into the τ=f(lx) relation. Example results of calculations of stress distribution in the joint of EP1000/4 and PP1000/4 belt splices were showed on figure 5.

**Fig. 4 Dimensional deformations diagram of adhesive joint component of a belt splice**

The results of measurements of basic properties of spliced belts, properties of the adhesive rubber as well as results of tests on stresses magnitude at outside connections of splices are presented in Table 1. Stretch resistance of belts (Rt) and elongations (εt) were determined according to EN ISO 283:2008 standard, modulus of elasticity of belt Mt according to EN ISO 9856:2005 standard, stretch strength of adhesive rubber according to ISO 252:2007 standard, modulus of adhesive rubber according to ISO 252:2007 standard at elongation of 100% reached after 3 hour of loading the samples with constant force.

In the tests both γ angles of adhesive joint and modules of joint rubber were determined after three hours after their stress because of big impact of creeping effect of those materials on their elongation during the initial period of stretching forces application.

The results of tests presented in table 1 were analyzed to present the relation of τ stresses versus Mt/Rt and Mg variables. The following form of this relation was assumed (3):

\[
\tau = C \frac{M_t}{R_t} \cdot \frac{M_g}{g^x}
\]

(3)

where:

- \(C\) – constant,
- \(x, y\) – exponents in demand.

This function was brought to the linear by taking a logarithm of both sides of the equation and thus the linear regression could be applied. The C, x and y values in demand were determined using STATGRAPHICS Centurion XV (v.15.2.06,
Correlation coefficient of this function in relations with the test results was R²=90.6%, while its corrected value was 86.9%. Since the obtained P value in the table of variance analysis ANOVA was lower than 0.05 (P-value=0.0027), the statistical dependence between the variables at the 95.0% level of confidence was identified.

The chart of function (4) is presented on figure 6.

3. Tests of fatigue life of splices

In the adhesive joint of splice subjected the cyclic fatigue loads, the heat is accumulated and therefore its temperature increases. The increase of temperature depends on the size and frequency of loads as well as on the type of the joint rubber and properties of the belt textile plies. Even at the same load conditions the temperature difference between individual splices may be up to tens of degrees. In such case comparing the test results for different types of splices is not possible. During the fatigue test it was assumed that the temperature of adhesive joint of splices being tested cannot exceed the range of 23°C ± 2°C. It was experimentally established that the above range of temperatures is possible to obtain under the following test conditions:

- Range of load form 5% to 20% of the belt strength
- Frequency of loads – 0.3 Hz
- Sinusoidal characteristics of loads
- Ambient temperature – 18°C

Temperature of joint was controlled using the pyrometer. The tested samples had a shape of small scull which was 50mm wide in the tested part and 100 mm wide in holding part. The total length of samples was 1150mm. After the analyze of test results of stress magnitude in the adhesive joints, the central notches of splices were shorten to 150mm. Outside notches had the standard length. The experiments were performed on the machine for dynamic tests of HC-25 type, produced by Zwick-Amster. As a criterion for evaluation the fatigue life of splices number of fatigue cycles causing the splice delamination equal 3mm. Basic parameters of tested splices and numbers of fatigue cycles obtained during the tests are showed in table 2. The total of 12 samples of splices were tested. The number of
fatigue tests showed in the table is the average for two tested samples. Table 2 contains also the properties of splices, which according to the previous analyze, had the essential impact on their fatigue life. The T adhesive strength between connected plies was determined according to ENISO 252:2008 standard.

Results of fatigue tests listed in table 2, were analyzed to present the relationships between number of cycles and \( R_t/M_t, M_g \) and \( T \) variables.

It was assumed that number of cycles may depend on 3 variables i.e. \( R_t/M_t, M_g \) and \( T \) and in STATGRAPHICS software the procedure of multiple regression model selection was used for them. It turned out that the best, from the point of corrected value of \( R^2 \), is the model based on two variables \( R_t/M_t \) and \( T \) (\( R^2 = 95.04\% \), and its corrected value is 91.74\%). As a result of non-linear multiple regression analyze, the following relations for number of cycles \( L_C \) was obtained:

\[
L_C = 123362 \left( \frac{M_t}{R_t} \right)^{1.90881} T^{1.92878}
\]  

(6)

The correlation coefficients received for the relationship (6) are: \( R^2 = 94.7\% \) and the corrected value is 91.2\%. Figure 7 presents the relationship described by the equation (6).

For practical purposes relationship (6) may be simplified to the form (7):

\[
L_C = 8.05 \left( \frac{M_t}{R_t} \right)^2 T^2
\]  

(7)

The correlation coefficients received for relationship (7) are: \( R^2 = 94.6\% \) and its corrected value is 94.6\%.

4. Summary

The test results presented in the paper showed how the stresses behave in the adhesive joint along each notch of multiply splices of conveyor belts.

It was identified that extreme values of these stresses occurring at splice joints depend mainly on elasticity modulus of the belt being connected, its strength and modulus of the adhesive rubber. Basing on the calculated relationship (4 or 5) producers of conveyor belts and materials used to join them, can select their parameters to have the maximal stresses in the adhesive joint at the level of 0.5 MPa, under the belt load amounting 15\% of its strength.

Fatigue tests of splices demonstrated that the essential impact on its durability has \( R_t/M_t \) the unit elasticity modulus of the jointed belts, and \( T \) adhesive strength of rubber used to join the plies.

Tests enable to define the relationship (6, 7) which allows to calculate the fatigue life of splice, measured in number of fatigue cycles causing the start of delamination of splice joints under the cyclic loads within the range from 5\% to 20\% of belt strength.

It was stated that depending on the strength parameters of jointed materials, the boundary number of fatigue cycles may be from several hundred to several thousands, what among other things, explain the reason of ungluing of numerous splices in working practice.

The deduced formulas calculating the number of \( L_C \) fatigue cycles enable to select very simply, the belts and adhesive materials properties to obtain the high fatigue life of splices and thus their better reliability.

Conducted research has indicated significant parameters affecting the strength and durability of multi-plies conveyor belt splices. It seems advisable to test using developed method more splices having different properties and construction. This will clarify any of the models shown in the article and allow on more accurate prediction of fatigue life of belt splices.

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### Table 2. Results of fatigue tests of splices

<table>
<thead>
<tr>
<th>Item</th>
<th>Material type of plies</th>
<th>Tensile strength belt ( R_t ) [kN/m]</th>
<th>Elasticity modulus of belt ( M_t ) [kN/m]</th>
<th>Adhesive strength of joint ( T ) [N/mm]</th>
<th>Number of fatigue cycles after which the splice is delaminated ( L_C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PP</td>
<td>1356</td>
<td>4639</td>
<td>6.3</td>
<td>440</td>
</tr>
<tr>
<td>2</td>
<td>EP</td>
<td>1050</td>
<td>12665</td>
<td>11.4</td>
<td>212 000</td>
</tr>
<tr>
<td>3</td>
<td>EP</td>
<td>997</td>
<td>14717</td>
<td>14.6</td>
<td>359 000</td>
</tr>
<tr>
<td>4</td>
<td>EP</td>
<td>1771</td>
<td>26577</td>
<td>9.2</td>
<td>145 000</td>
</tr>
<tr>
<td>5</td>
<td>EP</td>
<td>1942</td>
<td>18683</td>
<td>7.5</td>
<td>8600</td>
</tr>
<tr>
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<td>PP</td>
<td>1752</td>
<td>8697</td>
<td>12.1</td>
<td>1900</td>
</tr>
</tbody>
</table>

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![Fig. 7 Dependence of the number of cycles \( L_C \) of the independent variables \( M_t/R_t \) and \( T \) (6)](image-url)
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