Mechanical Properties of the Materials Making up the Conveyor Belt Structure

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Abstract. Belt conveyors, equipped with belts designed for transporting materials and finished products are used in many industries. They allow to transport delicate items, for example made of glass, heavy products, such as canned food products and lightweight items, such as cardboard boxes. For this reason, the conveyor belts must, besides transferring power, ensure adequate conditions of transport for the conveyed materials without compromising the service life of the belt. Homogenous belts may not be capable of meeting all these requirements at a time. Composite belts, composed of the load-bearing layers and covering materials adhered thereon with the purpose to modify the surface properties, can be an option of choice in such cases. The described experiments were carried out on the respective materials making up composite belt joints as part of the research efforts related to the PhD thesis on adhesive bonding of composite belting materials. The strength tests were carried out on dumbbell-shaped specimens that were prepared from the load-carrying layer of synchronous polyurethane belting, the facing materials, namely polyamide fabric and polyurethane foam and the polyurethane adhesive used to join these layers. The differences in the parameters describing the surface properties, i.e. hardness and roughness were also checked. The experimental results were used to determine the material and strength properties of the components and the resulting differences were analysed.

1 Introduction

Belt conveyors are used for transporting products or materials over pre-defined distances. They are used in papermaking, textile, glass, wood, food and medical industries. Their operation relies on positive-fit/ friction connection between the belt and the pulley, as well as on the appropriate properties of the carrying surface of the belt. Synchronous (toothed) belts are used in these application, which, in the absence of a separate intermediate link, combine carrying and power transfer functions. Composite construction is required to satisfactorily fulfil both these functions. Besides, materials used for conveying food and pharmaceuticals must feature chemical and biological resistance. In the case of lightweight materials perforated belts may be needed to enable vacuum conveying [1]. Fragile materials require a sufficiently soft and smooth surface of the belt. Extra strength is required for belts.
which combine carrying and power transmission functions. The required strength and appropriate properties of the carrying surface can be attained by belts of composite construction (Fig. 1), composed of:

- tension member, which carries the loads acting on the belt and defines its overall strength, embedded in the belt body, most often made of: steel, kevlar, synthetic fibres, polyester fabric;
- belt body, namely the base material of the belt surrounding the tension member and, in the case of synchronous belts, it used for making the belt teeth and the backing layer over the tension member;
- facing (optional) is an additional layer applied on the belt backing layer and its teeth in order to obtain the desired value of the coefficient of friction; it is of practical importance for transporting specific groups of materials; facing material can be applied either during or after moulding of the belt, in the latter case bonded, for example, with adhesive.

![Fig. 1. Reinforced polyurethane belting, including facing: A – polyamide fabric applied on the backing and on the toothed side during moulding (tension member is not visible on the picture but it is present inside the belt body), B – PU foam bonded with adhesive to the belt backing; 1 - facing, 2 - bonding layer 3- backing layer (part of the belt body), 4- tension member, 5- teeth (part of the belt body).](image)

The fabric facing is applied on the belt teeth during moulding. This method is chosen due to the complex shape of the teeth and the problems involved in other possible methods of application [12]. Conversely, the carrying cover made of polyamide fabric can be applied either during moulding or bonded with adhesive to the finished belting. Polyurethane foams are most often bonded with adhesive.

In the case of bonding with structural adhesives, the bond should attain the specified strength and deliver the required functionality. Bonding with glue involves two types of interactions: cohesion, i.e. internal binding of particles (it occurs independently in the adhesive and in the adherends) and adhesion, i.e. physical attraction or binding of two different substances (for example the adhesive and the adherend). Adhesion comprises two interaction types: mechanical and chemical (proper). Mechanical adhesion is based on the penetration of adhesive into the surface irregularities of the adherend and positive-fit/friction connection, which develops when the adhesive has set. Proper adhesion occurs at the molecular level and is based on the mutual attraction of molecules of the two adherends and on the development of chemical bonds [15]. The factors relevant to the bond strength include selection of adequate adhesive for the specific adherends, preparation of adherend surfaces, preparation of the adhesive, adhesive application technique, thickness of adhesive layer, drying time, pressure, temperature and, finally, the method of loading the obtained adhesive bond [7,9,10,13,14]. The thickness of the adhesive layer has a significant effect on the bond strength and the range of this thickness given in the literature ranges from 0.05 mm up to as much as 4 mm, depending on the type of adhesive and the adhered materials [6,7,8,9,10,14]. The second in the order of importance parameter is the width of the layer of
adhesive [9,10]. Also relevant to the adhesive bond quality is the condition of the adherend surfaces, including roughness and cleanliness, while the chemical composition of adhesive and the remaining material must support development of binding forces. Moreover, conveyor belts are exposed to varying loads. For this reason, before a specific type of adhesive is used in mass production, chemical compatibility and the actual bond strength are tested for the adherends concerned.

The purpose of the experiments carried out as part of the PhD thesis research work was to determine the parameters relevant to adhesive bonding of polyurethane, reinforced synchronous belting and PU or polyamide fabric facing and the influence of these parameters on the bond strength, in particular determined by rolling of the belt around a circle. There is a noticeable interest in issues related to increasing process efficiency in the literature [18-21,25,26]. Research is being carried out, among other, to improve processes related to belt perforation [1,22], as well as to modification of machines carrying out the process of gluing plastics [13,23,24] and power transmission through belts [19]. Experimental tests and numerical simulations methods are used to improve the processes [22,26,27].

In the first step the selected properties of the structural materials making up the bonded joint, part of the composite construction of the belt were investigated. These properties enable comparing and distinguishing the properties of the selected materials which may be relevant to making adhesive bonded joints. Particular attention was paid to the surface properties, including hardness and roughness, and to the determination of breaking stress values for the respective materials. The results of the basic tests will enable comparing the information provided in the manufacturer’s brochures and the generally available data concerning the characteristic properties of the materials in relation to the actual properties of the selected materials.

2 Material properties of the structural components of the analysed belts

Preliminary determination of the material properties was carried out on the materials that make up the composite structure of the conveyor belts under analysis. These include: steel or kevlar reinforced PU belting, polyurethane foam and polyamide fabric (used as facing), Bonapur RZ45 or Bonapur PU adhesives (Fig. 2).

![Fig. 2. Materials used in the tests: 1- polyamide fabric, 2- PU foam, 3- kevlar reinforced PU belting, 4- steel rope reinforced PU belting, 5- Bonapur RZ45 adhesive, 6- Bonapur PU adhesive.](image)

The backing of the reinforced PU synchronous belting is joined with the PU foam or polyamide fabric facing by bonding with adhesive. These materials, except for the fabric and the reinforcement, are polyurethanes. From the chemical composition viewpoint all the adhered materials (reinforcement is not bonded with adhesive) are built of carbon and hydrogen molecules, and thus are chemically similar. Polyurethane is a plastic of strongly varied properties, which depend on the mix composition and the obtained structure. The characteristic features of this material include:
high elasticity with 100-800% elongation at break,
wide range of hardness of 35-96 ShA,
high level of chemical, ageing and abrasion resistance,
coefficient of friction decreasing with the increase of hardness [11],
possibility to obtain a very smooth surface,
damping of vibrations,
density in the range of 1.1 – 1.28 g/cm³,
operation at the 30 - 80 ºC temperature range,
tensile strength of 20 – 70 MPa.

Selected properties of synchronous polyurethane belts can be obtained from the product brochures. The tensile strength, given in the data sheets, depends on the tension member material, belting width, which defines the number of cords in the tension member (the strength increases when the belt width is increased) and on the belt type – endless, joined or open-ended. The breaking strength of a 10 mm wide belt with the tension member made of steel ropes is 2,560 N for endless belt and 640 N for joined belt [3]. Surface roughness and hardness are not given in this brochure.

The polyurethane foam chosen for this research is sold under the trade name Polythane D15. According to the product brochure [2, 3] its hardness is ca. 70 Shore A and depends on the foam thickness. If features a high abrasion resistance and is resistant to oils, grease and UV radiation. The cells are closed on one side, making the surface coarse to the touch and devoid of hollows. On the other side of the belt the surface is smooth and includes hollows at the cell locations. The product brochure gives the tensile strength values.

The purpose of polyamide fabric facing is to reduce the wear and tear of the belt [4]. It decreases the friction coefficient, which is important for appropriate teeth/ pulley interaction. Facing is particularly required where sharp edged materials are conveyed, owing to its resistance to tearing and wearing out [3,4,5]. It is also waterproof. More detailed information was not found in the available product brochures.

In the data sheets the manufacturers of adhesives pay particular attention to the presence of harmful substances, the application method and selected characteristic features of the products. These data are compiled in Table 2.1 for Bonapur PU and Bonapur ZR 45 [16,17].

The general data concerning the materials and the information given in the product brochures are not sufficient to fully determine the properties of materials, which have been identified as being relevant to the glue bonding process. Therefore, it was decided to determine the selected properties of the respective structural materials making up the composite belt construction through preliminary testing.
Table 1. Selected properties of BONAPUR PU and BONAPUR RZ45 adhesives.

<table>
<thead>
<tr>
<th>Property</th>
<th>Bonapur PU</th>
<th>Bonapur RZ45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Colourless, turbid, viscous liquid</td>
<td>Viscous liquid</td>
</tr>
<tr>
<td>Odour</td>
<td>Acrid, acetone-like</td>
<td>Ester-like</td>
</tr>
<tr>
<td>Freezing temperature</td>
<td>&lt;0°C</td>
<td>&lt;0°C</td>
</tr>
<tr>
<td>Flash point</td>
<td>&gt;23°C</td>
<td>&gt;23°C</td>
</tr>
<tr>
<td>Autoignition temperature</td>
<td>&gt;420°C (acetone)</td>
<td>&gt;420°C (acetone)</td>
</tr>
<tr>
<td>Relative density</td>
<td>0.856 g/cm³ @ 40°C</td>
<td>0.868 g/cm³ @ 40°C</td>
</tr>
<tr>
<td>Solubility</td>
<td>Sparingly soluble in water</td>
<td>Sparingly soluble in water</td>
</tr>
<tr>
<td>Kinematic viscosity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic viscosity</td>
<td>KF 6 mm, efflux time of 50 ml: 55-62 sec.</td>
<td>650 mPa</td>
</tr>
<tr>
<td>Dry residue</td>
<td>16-18 wt%</td>
<td>21.15 wt%</td>
</tr>
<tr>
<td>Specified harmful substances</td>
<td>Acetone, toluene, butane-1,4-dicarboxylic acid</td>
<td>Acetone, ethylene acetate, methyl ethyl ketone</td>
</tr>
<tr>
<td>Peel strength according to PN-ISO 11339, canvas-canvas material:</td>
<td>initial: at least 2.5 kN/m</td>
<td>No data available</td>
</tr>
<tr>
<td>Cure speed</td>
<td>At least 48h</td>
<td>At least 24 h</td>
</tr>
<tr>
<td>Application method</td>
<td>With a roller or paintbrush</td>
<td>With a spray gun</td>
</tr>
<tr>
<td>Required thickness of adhesive layer</td>
<td>Not specified, two layers should be applied on porous substrates</td>
<td>Not specified, the amount should produce adequate thickness, two layers should be applied on porous substrates</td>
</tr>
<tr>
<td>Joining conditions</td>
<td>Press evenly for ca. 20 sec. with a pressure of 0.4 – 0.5 MPa</td>
<td>Press evenly and firmly</td>
</tr>
<tr>
<td>Activation temperature</td>
<td>75-85°C</td>
<td>40-50°C</td>
</tr>
</tbody>
</table>

3 Measurements and experiments

3.1 Microscopic evaluation of the surface of materials

The texture and quality of the surfaces of the selected materials (belts, adhesives, PU foam and polyamide fabric) were evaluated by means of CELESTRON microscope with integrated 1.3 Mpx CMOS digital camera of 1280x1024 resolution (Fig. 3). The image is displayed directly on the monitor and recorded.
The specimens were laid on a flat surface. The microscope, equipped with a camera, was positioned over the sample so that the shield touched the sample and then focus was adjusted. After the surface was viewed, representative images were recorded (Fig. 7).

### 3.2 Measurement of the surface roughness

The surface roughness was measured with Hommel Tester T1000 (Fig. 4) measuring instrument. The test section was 4.8 mm long and the measurement range was 80 µm. A filter in compliance with ISO 11562 was applied. T1E roughness probe was chosen as the measurement instrument. The measurement results are displayed on the screen as a diagram and on completion the values of the selected surface parameters are also displayed. The tested materials were laid on a flat surface. Any dirt was removed. The part of the apparatus including the sensor was moved to the test position (Fig. 4) and ten measurements were done for each material.

This test was carried out on kevlar and steel reinforced PU belts, polyurethane foam from the side with partly open cells and adhesives. The surfaces of the fabric and the polyurethane foam from the closed cells side were not tested. In the first case, it was due to the non-uniform surface composed of elastic loops of threads, on which the probe tip
caught during movement. In the second case the probe was not a suitable tool due to inappropriate measurement range.

### 3.3 Measurement of the surface hardness of the tested materials

Surface hardness of the tested materials was measured with a Shore A dial durometer (Fig. 5). The materials were placed on a flat surface. The synchronous belt was engaged on the teeth of another belt to obtain stable support of the surface (Fig. 5). Ten measurements were carried out for each material, except for the polyamide fabric and adhesive, for which measurement of hardness was impracticable due to the nature and thickness of the material. Hardness measurements were carried out on the samples with facing fabric applied during moulding and with the facing fabric and foam adhered before the test. The fabric and foam were adhered with Bonapur RZ45 adhesive. A thin layer of glue was applied on both surfaces, allowed to dry for the prescribed time and then the adherends were pressed firmly together. The measurement was carried out after four days.

![Fig. 5. Pictures showing the hardness tester positions during measurements.](image_url)

### 3.4 Measurement of the force and elongation at break

The tensile strength test was carried out due to the absence of the details on the breaking force and elongations at break of the tested materials. The recommendations of EN ISO 527-1, 527-2 were applied. Five dumbbell-shaped specimens were cut out from each material (Fig. 6) by means of a dumbbell-shaped die, while samples of glue and fabric, due to low stiffness of the material were cut out with scissors, using a template.
The adhesives are supplied in liquid form. The mechanical properties and texture were also checked on the specimens of hardened adhesive not bonded to substrate (Fig. 6). These samples were produced by pouring and spreading with a spatula some amount of adhesive on a flat surface, previously coated with silicone as a bond breaking layer. In this state the adhesive was allowed to cure for 48 hours. After that time, it was removed from the silicone coated surface. In this way a film of glue was obtained. The aim was to make this layer as thin as possible. However, this method of application did not ensure uniform thickness all over the surface. Moreover, the samples included visible air bubbles (Fig. 7). The samples produced in this way were used in the research because adhesive is used for binding and not as a separate material.

All the specimens were measured before the test (Table 2). They were all 10 mm wide, the measurement section was in all cases 110 mm long and thicknesses were different, depending on the material. The primary role in ensuring the belt strength is played by the tension member, and therefore, the tension member dimensions are given and the complex shape of the belt has been ignored. The greatest thickness variation was obtained for the glue specimens. The Table 2 gives the smallest thickness and the thickness range over the entire length of the specimen.

The tests were carried out on MTS Insight apparatus with the force measurement range up to 50 kN. The specimens were clamped in jaws, the sensor readouts were zeroed and the measurement was started at a rate of 500 mm/min. The same speed was used for all the specimens. Except for the adhesive specimens, the test was continued until failure of samples. Specimens of glue that were thicker than 0.05 mm did not break due to a limited measuring range of the tester and their extensibility.
Table 2. Dimensions of specimens.

<table>
<thead>
<tr>
<th></th>
<th>PU foam</th>
<th>Polyamide fabric</th>
<th>Steel rope</th>
<th>Kevlar</th>
<th>Bonapur PU adhesive</th>
<th>Bonapur RZ45 adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width [mm]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Thickness [mm]</td>
<td>2.15</td>
<td>0.25</td>
<td>0.5 mm</td>
<td>0.7 mm</td>
<td>Specimens: 3x0.05, 2x0.06 [mm] (0.05 - 0.18)</td>
<td>0.05 (0.5 - 0.27)</td>
</tr>
<tr>
<td>Measurement section length [mm]</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
</tbody>
</table>

4 Results

The microscope images of the materials (Fig. 7) show varied surface texture.

![Microscope images](image)

**Fig. 7.** Microscope images of the tested materials: A1 – polyurethane foam, side with closed cells, A2 – polyurethane foam, side with partly closed cells, B – polyamide fabric, C – Bonapur PU adhesive, D – Bonapur RZ45 adhesive, E- kevlar reinforced PU belt, F- steel rope reinforced PU belt.

On one side, the polyurethane foam has closed cells (Fig. 7 A1) and is coarse to the touch. On the other side the pores are visible (Fig. 7 A2), the surface shines and is less rough (roughness could be measured only on this side due to measurement range limitation of the instrument). The polyamide fabric (Fig. 7 B) includes characteristic loops, which make roughness measurement impracticable. This structure enables penetration of the material by substances. The material is not uniform and it is not possible to determine if the loops are the same at every point. The tested adhesives, namely Bonapur PU (Fig. 7 C) and Bonapur RZ45 (Fig. 7 D), which were allowed to set without binding to any material and without
applied pressure contained air bubbles. These adhesives set by evaporating the solvents, and therefore they were left in the open air. Also the surfaces of belts vary considerably. The body of the kevlar reinforced belt (Fig. 7 E) is made of transparent, smooth polyurethane through which reinforcement can be seen. The steel rope reinforced belt has opaque surface with visible texture (Fig. 7 F).

The tested materials differ also in terms of hardness (Table 3) and surface roughness (Table 4). Since the polyamide fabric and the layer of adhesive were too thin for hardness measurement they were bonded with adhesive to the belt.

Table 3. Results of Shore A hardness test.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU foam</td>
<td>72</td>
<td>71.5</td>
<td>73</td>
<td>72</td>
<td>70</td>
<td>70</td>
<td>73.5</td>
<td>72</td>
<td>69</td>
<td>72.5</td>
<td>71.55</td>
</tr>
<tr>
<td>Steel rope reinforced belt</td>
<td>90</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>89</td>
<td>90</td>
<td>90</td>
<td>92</td>
<td>92</td>
<td>90.7</td>
<td></td>
</tr>
<tr>
<td>Kevlar reinforced belt</td>
<td>92</td>
<td>90</td>
<td>93.5</td>
<td>92.5</td>
<td>93</td>
<td>92.5</td>
<td>91.5</td>
<td>93</td>
<td>90</td>
<td>92.1</td>
<td></td>
</tr>
<tr>
<td>Belt faced with fabric during moulding</td>
<td>93</td>
<td>92.5</td>
<td>93</td>
<td>94</td>
<td>92.5</td>
<td>94</td>
<td>93.5</td>
<td>93.5</td>
<td>94</td>
<td>93.3</td>
<td></td>
</tr>
<tr>
<td>Belt with the fabric adhered before the test</td>
<td>76</td>
<td>77</td>
<td>76</td>
<td>79</td>
<td>75</td>
<td>76</td>
<td>78</td>
<td>76</td>
<td>78</td>
<td>79</td>
<td>77</td>
</tr>
<tr>
<td>Belt with the foam adhered before the test</td>
<td>67</td>
<td>63</td>
<td>69</td>
<td>66</td>
<td>64</td>
<td>65</td>
<td>69</td>
<td>65</td>
<td>66</td>
<td>67</td>
<td>66.1</td>
</tr>
</tbody>
</table>

The hardness values are similar for the two belts. According to the results, the foam is softer than the belts and its hardness value is close to the value given by the manufacturer (ca. 70 Shore A). Bonding of the fabric facing during moulding of the belt slightly increases the surface hardness while adhering the fabric with adhesive has the opposite effect, i.e. decreases the surface hardness of the material. Similarly, also the surface of polyurethane foam when tested separately was harder than the foam adhered to the belt. This suggest that the hardness of adhesive is lower than the hardness of the facing material, this resulting in a decrease of the overall surface hardness. Hardness variation on the surface of belt facing can be attributed to uneven spreading of adhesive and indicate that the adhesive layer thickness has a bearing on the surface hardness value.

The surface condition of the materials, including roughness, influences adhesion. Table 4 gives the roughness data of the tested materials.

The lowest roughness value was obtained for the kevlar reinforced belt. The highest roughness was obtained for the polyamide fabric or the closed cell foam surface, where the Rz value exceeded the measurement range of the instrument. The surface texture images in Figure 7 are representative of the obtained roughness values. Looking at the values of Ra, Rz and Rmax parameters we see a considerable variation in the surface roughness between the belts. A higher roughness means a greater surface area of the element and a presence of hollows enhancing mechanical adhesion. However, there are guidelines in the available literature indicating that surface roughness should be maximised to improve bond performance.

The tensile tests carried out on dumbbell-shaped specimens (Table 1, Figure 6) enabled determination of their percent elongation at break and average breaking stress. Table 5 gives the average results from 5 measurements. Note, however, that some glue specimens, thicker than 0.05 mm did not break in the test, and therefore, their elongation at break could actually be higher. The relationship between elongation and force is shown in the figures below.
The point at which the force and elongation values start to increase more rapidly is clearly evident (marked with a vertical line) on the breaking force diagrams (Fig. 8 and Fig. 9), in particular for steel rope reinforced belts and for K6 and K7 specimens of kevlar reinforced belts. It is the point when the tension member was broken apart and then pulled out from the belt body, which becomes extended at the same time. In the case of curves K6 and K7 the tension member was pulled out from the belt body, which is shown in Fig. 8 below. These specimens are presented for reference only and they were not taken into account for the purpose of stress determination.

The tension members were broken after elongation by slightly above 5.3 mm in the case of steel cord and slightly above 5.2 mm in the case of kevlar reinforcement, this being a ca. 5% elongation. Specimens L1 and L3 contained one rope more than the other specimens, which was noted after failure of specimens. The cause of that was the method used to cut


<table>
<thead>
<tr>
<th>No.</th>
<th>Rmax [µm]</th>
<th>Rz [µm]</th>
<th>Ra [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>83.6 45.38 2.85 47.7 1.38</td>
<td>63.77 13.63 1.77 35.63 1.2</td>
<td>12.11 3.027 0.402 5.782 0.179</td>
</tr>
<tr>
<td>2</td>
<td>102.7 55.81 1.45 53.15 1.22</td>
<td>65.03 26.62 0.94 40.27 0.92</td>
<td>11.5 6.988 0.2 6.82 0.157</td>
</tr>
<tr>
<td>3</td>
<td>75.94 16.39 3.59 52.22 1.94</td>
<td>56.52 9.22 1.46 37.65 1.23</td>
<td>11.88 2.655 0.266 6.963 0.206</td>
</tr>
<tr>
<td>4</td>
<td>105.4 8.94 26.7 39.57 1.09</td>
<td>58.71 5.39 11.66 31.7 0.9</td>
<td>10.95 1.307 3.172 5.358 0.168</td>
</tr>
<tr>
<td>5</td>
<td>73.29 14.5 15.85 48.38 1.1</td>
<td>57.8 9.13 3.05 39.2 0.95</td>
<td>12.84 2.226 0.981 6.355 0.172</td>
</tr>
<tr>
<td>6</td>
<td>67.96 32.99 5.22 51.04 1.23</td>
<td>45.72 14.03 3.11 39.31 0.92</td>
<td>8.347 2.315 0.658 6.054 0.156</td>
</tr>
<tr>
<td>7</td>
<td>85.38 5.14 6.21 40.03 1.02</td>
<td>59.25 3.44 2.21 35.49 0.91</td>
<td>11.1 0.704 0.246 6.203 0.146</td>
</tr>
<tr>
<td>8</td>
<td>53.4 32.61 4.57 38.14 1.1</td>
<td>46.17 9.34 2.04 32.77 0.92</td>
<td>9.348 1.536 0.341 5.892 0.15</td>
</tr>
<tr>
<td>9</td>
<td>75.98 13 1.19 42.42 1.46</td>
<td>49.6 5.27 0.79 34.1 1.01</td>
<td>9.113 1.06 0.159 6.287 0.183</td>
</tr>
<tr>
<td>10</td>
<td>62.27 42.12 19.69 41.34 1.25</td>
<td>50.45 17.91 8.61 33.01 1.05</td>
<td>10.96 4.175 2.191 6.166 0.177</td>
</tr>
</tbody>
</table>

Table 5. Average elongation at break and breaking stress of the specimens of composite materials subjected to the tension test.

<table>
<thead>
<tr>
<th>Elongation at break [%]</th>
<th>Kevlar reinforced belt</th>
<th>Steel rope reinforced belt</th>
<th>Polyurethane foam</th>
<th>Polyamide fabric</th>
<th>Bonapur PU adhesive</th>
<th>Bonapur RZ45 adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.44</td>
<td>4.9</td>
<td>149.22</td>
<td>94.41</td>
<td>367.55</td>
<td>403.53</td>
<td></td>
</tr>
</tbody>
</table>

| Breaking stress [MPa]  | 103.79 | 115.1 | 4.86 | 61.9 | 23.31 | 19.66 |

Fig. 8. The tension member pulled out from the belt body.
out the specimen. The maximum forces that cause complete breaking of the belt are close to the values given by the manufacturer.

![Applied force vs. elongation of steel rope reinforced belt specimen](image1)

**Fig. 9.** The relationship between the applied force and elongation of the steel rope reinforced belt.

![Applied force vs. elongation of kevlar reinforced belt specimen](image2)

**Fig. 10.** Relationship between the applied force and elongation of the kevlar reinforced belt. In the case of samples K1-K5 reinforcement was broken apart and in the case of specimens K6 and K7 it was pulled out from the belt body.

In the case of adhesive specimens, the breaking force and the maximum force reached before the end of the measuring range were referred to the smallest specimen cross-section. The graphs show the variation of the force values, which is caused by a considerable measurement inaccuracy at small values in relation to the 50kN measurement range of the tester. Among the adhesives, the highest breaking force values were obtained for Bonapur RZ45. Besides, two out of the total number of five specimens did not fail till the end of test. As compared to the belting specimens, the elongations at break of adhesive specimens were large, i.e.: 360% for Bonapur PU and 400% for Bonapur RZ45.
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Polyurethane foam (Fig. 13) features a high value of the elongation at break, i.e. up to 150%. The highest repeatability of results was obtained in this case, as can be seen from the graph. The breaking stress values are smaller than in the case of belts, yet greater than obtained for adhesive. The broken specimen exhibited visible cracks above the fracture (Fig. 14), most frequent right at the fracture and decreasing in number towards the holder.

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Fig. 14. Visible cracks in the smooth part of the PU foam specimen after failure.

The elongation at break of the tested polyamide fabric was 94% on average. It is worthwhile noting that polyamide fabric is not a uniform material. During the test cracking of fibres was observed, followed by pulling out the cords from the belt body, represented on the graph (Fig. 15) by a decrease of the applied force and a slight elongation at the end of the curve.

Fig. 15. Relationship between the applied force and elongation during extension of the polyamide fabric specimen.

5 Conclusions

The following conclusions were drawn and observations were made on the basis of the preliminary tests and investigation of the selected properties of the materials under analysis:

1. Polyurethane structural materials, which make up the composite structure of the examined belts, strongly vary in terms of the mechanical properties and the surface texture parameters, which can considerably influence the quality and strength of the adhesive joint.

2. Use of chemically alike materials has a good effect on the development of adhesive bonds between the adherends.

3. The foam hardness and belt strength values given by their manufacturers are close to the results obtained in this research.

4. The highest value of roughness Ra was obtained for polyurethane foam, yet it must be noted that the apparently high roughness of the polyamide fabric could not be measured with the instrument used in this research.

5. The surface roughness values of belts varied strongly despite their body being made of polyurethane while hardness values were similar.
6. The surface hardness of the belt decreases when foam of a smaller hardness is adhered on the belt backing surface.
7. When polyamide facing fabric is applied during moulding of the belt the surface hardness increases slightly and when the fabric is adhered on the moulded surface the hardness decreases due to the presence of a softer adhesive layer.
8. Changing the surface hardness of the belt one should consider not only the hardness of facing (foam or fabric) but also the effect of the adhesive layer thickness on the final surface hardness value; the influence of the adhesive layer on the final surface hardness was observed in the case of 2.15 mm thick foam and 0.25 mm thick fabric.
9. The research confirmed the relationship of the tension member strength, for which the highest breaking stress values were obtained among the tested materials, and the strength of the belt as a whole.
10. The variation in the breaking force values obtained for two specimens of steel rope reinforced belt is caused by a smaller number of ropes in the specimens cut out from a wider belt.
11. In the test carried out on dumbbell-shaped specimens the tension member was pulled out of the belt body, which will not happen in the case of endless belt until the tension member failure.
12. The smallest elongation obtained for the tension member means that elongation and failure of the remaining parts of the belt will occur after its failure.
13. Much greater values of elongation at break were obtained for the polyurethane foam, adhesives and polyamide fabric, as compared to the tension cord elongation, and therefore, we can expect that joining these elements with the belt backing surface will not decrease its elasticity and the possible looping range over the pulley.
14. Evenly applied pressure, as recommended by the adhesive manufacturer, enables obtaining a uniform layer of adhesive free of air bubbles, which is not the case when the adhesive is left to dry in the open air.
15. We can expect that cracking of the foam above the fracture in the tension test can occur also during bending and tensioning of a foam faced belt over the timing pulley.

The experimental results enabled us to draw conclusions and guide future research on making and durability of adhesive joints between the conveyor belt body and facing. Therefore, the objectives of future research should include determination of:
- the effect of surface roughness on the strength of the adhesive bond,
- absorption of the polyamide fabric,
- the effect of the pressing force and pressing time on the adhesive layer thickness,
- the effect of the adhesive layer thickness on the bond quality,
- change of surface hardness, depending on the adhesive layer thickness,
- the effect of bending the belt over the pulley on deterioration of the adhesive bond and the belt backing layer.

References

17. Product data sheet of Bonapur PU adhesive.