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LABORATORY TESTING OF CONVEYOR TEXTILE BELT JOINTS USED IN UNDERGROUND MINES

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Abstract: In order to achieve the high standards of safety and operational reliability required of belt conveyors, there is a requirement for systematic testing of conveyor belts and their joints. This article describes joint testing methods and presents an analysis of the causes of reduced strength of multi-ply belt joints. Testing was carried out at the Belt Conveying Laboratory (LTT) of Wroclaw University of Technology. Presented here is a proprietary method for the measurement of stress distribution in conveyor belt adhesive joints.

Keywords: conveyor belt, fabric belt joints, joint testing

INTRODUCTION

In belt conveyor systems the most costly component to maintain is the belt itself.

Its operation often determines the reliability of the entire system. Apart from fire and electrical safety requirements it should, therefore, meet specific strength and performance requirements. For belts with a textile core intended for use in underground mines, these requirements are included in the standard PN-EN ISO 22721:2009 and for belts with steel cables – standard PN-EN ISO 15236-3:2009 (Hardygóra et al., 2010).

During operation of the conveyor, the belt is subjected to varying loads. It is cyclically loaded and unloaded along the length of the line and unevenly loaded while passing through intermediate sections and over conveyor drums. Belt covers become

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worn down, caused by the material handled, roller assemblies and cleaning systems. Another factor in the ageing of the rubber and the whole belt are the environmental conditions. All of the above-mentioned factors contribute to degradation of the functional capability of the belt, i.e. the belt undergoes natural wear and tear. The question is, how fast will this process occur? The rate of wear is dependent on operating conditions and the selection of belt properties appropriate for those conditions. Experience shows that belt deterioration is also affected by adherence to operating instructions, i.e. following the conveyor's operating manual (in particular, loading of the belt along the conveyor's axis, not overloading it, providing adequate initial tension) and keeping the conveyor in good overall condition (especially the rollers and cleaning systems). In conclusion, belt wear is primarily influenced by staying within these operational limits.

The weakest element in a belt loop is its joint. The joint strength depends on its type, the joining method used and the quality of the joint. The most appropriate solution is belt joining with vulcanisation methods, or hot or cold glueing, since it provides the best strength and durability of joints. Belt joints are tested to determine their durability and structural quality. The Belt Conveying Laboratory of Wrocław University of Technology has worked for years on improving belt joining methods, and is the only institution in Poland that carries out belt verification by performing strength tests on full length belt joints. This method is consistent with the guidelines of the PN-C-94147:1997 standard and it involves the stretching of a full-length sample to point of failure on a horizontal strength-testing machine.

TYPES OF CONVEYOR BELT JOINTS

Conveyor belts are produced in sections of up to 300 m, which is why on the conveyor they are connected in a loop. The following joint types are used for joining conveyor belts (Banaszak and Laska, 2006):

- vulcanised (hot) – for fabric belts: single-ply, two-ply and multi-ply, and for belts with steel cables,
- adhesive (cold) – only for two- and multi-ply fabric belts,
- mechanical – treated as temporary joints.

When making adhesive or vulcanised joints on multi-ply belts, belt endings are prepared in the same fashion. This involves stripping off the rubber covering from each ply on a section of each tier (tier 1: single-ply cover, etc.) The length of a tier depends on the strength of the ply in the belt core. These prepared endings are evenly covered with a layer of adhesive, then evenly rolled with the correct pressure. Joint preparation diagram of multi-ply belts is presented in Figure 1.

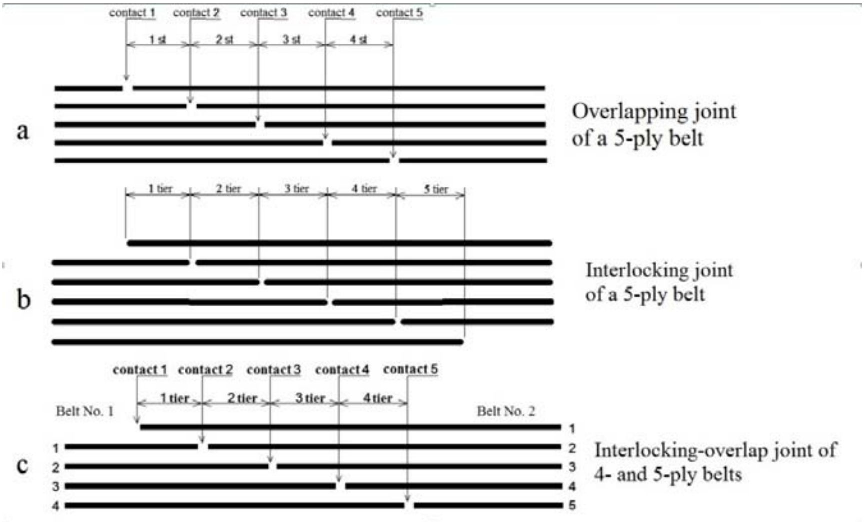

Fig. 1. Typical construction diagrams for multi-ply belts

LABORATORY TESTS

The rate of wear of conveyor belt joints is influenced by the strength of the belts being joined, proper selection of jointing materials, but mostly by the quality of the joint (Bajda et al., 2013; Hardygóra and Komander, 1997; Hardygóra et al., 2006; Komander et al., 2011). The LTT laboratory conducts strength testing of conveyor belt joints for compatibility with PN/C-94147 and EN-ISO 112 standards to determine:

- the tensile strength of a joint,
- the delamination strength of an adhesive joint,
- the shear strength of an adhesive joint.

In the event a tested joint does not reach the strength required by the standard, based on an analysis of the results and any necessary additional tests, it is possible to determine the cause of such an occurrence. There are several possibilities, e.g. the wrong belt jointing materials, wrong quality of belt, faulty vulcanising equipment or procedural mistakes. Laboratory tests make it possible to determine the stress distribution in an adhesive joint, with which corrections of the joint structure can be implemented, or the vulcanisation materials changed, in order to reduce the stresses occurring (Błażej and Hardygóra, 2004; Błażej et al., 2004; Komander et al., 2012; Mazurkiewicz, 2009 and 2012).

The structure of a conveyor belt is based on appropriate delamination strength between the individual belt plies. This strength cannot be so low as to cause delamination between belt elements during normal use. Too high a delamination value between the covers and the core and the plies themselves is undesirable due to difficulties in the preparation of belt endings for jointing.

Keeping in mind the fact that joints are the weakest element of the belt on a conveyor system, efforts are made to optimise jointing methods. For this purpose tests are carried out to determine the shear strength between the friction rubber layer and the ply.

The tensile strength of fabric belt joints is determined with samples 200 mm wide and stretched lengthwise as per the requirements of PN-C-94147:1997. Such tests are performed on a purpose-built tensile strength testing machine as shown in Figure 2. Tested joints can have different structures, which is shown schematically in Figure 1.

In all types of multi-ply belt joints stress concentrations can occur at locations of ply discontinuities. Irrespective of the loss of a single ply, there also occurs a strength loss caused by a stress concentration at the ply contact point, which is defined in the standard PN-C-94147:1997 by a factor of 0.85.

Strength test results are verified against the required strength specified in the standard PN-C-94147: 1997 using the equation:

$$R_p = 0{,}85 \cdot R_r \cdot \frac{n_z - 1}{n_t}, \quad \text{kN/m}$$

where: R_p – joint tensile strength in kN/m, R_r – belt tensile strength in kN/m, n_z – number of plies in the joint, n_t – number of plies in the belt.

If belts with differing strength or number of plies are being joined, joint strength is calculated at both external contact points of the plies, and the lower values are used for comparisons.

Fig. 2. Tensile testing machine ZP-40 for belt joints

TESTING STRESS DISTRIBUTION IN AN ADHESIVE JOINT

On the basis of strength tests of fabric-rubber belt joints conducted so far at the LTT, a number of factors acting directly on their uniaxial tensile strength have been noted (Hardygóra et al., 2006). In use observation shows that joints are delaminated at the external point-of-contact areas. This is evidenced by the fact that due to fatigue loads the adhesive joint is destroyed sooner than the plies. Increasing durability of the adhesive joint is then a crucial element influencing the improvement of overall joint durability. This was the primary reason for undertaking research aimed at determining which properties of conveyor belts and materials for joining them affect the stress intensity in adhesive and vulcanised joints.

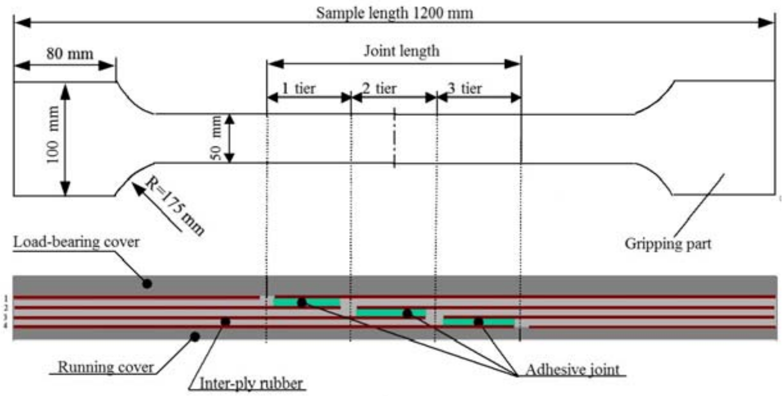

Fig. 3. The shape of a belt joint sample for determining deformations in an adhesive joint

The stress testing method involves conducting measurements of the angle of non-dilational strain of the contact point in adhesive joints (Fig. 3) subjected to tensile load, and then converting the results into units of stres (Błażej and Hardygóra, 2003; Hardygóra et al., 2012; Research Project, 2004). The γ angle is defined as the joint deformation quotient ΔS and the distance g between the plies (n and n+1) being displaced (Fig. 4).

$$\operatorname{tg} \gamma = \frac{\Delta S}{g}$$

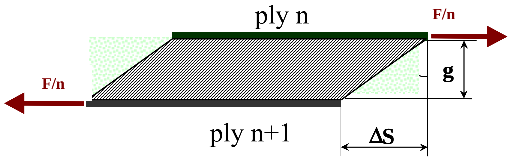

Fig. 4. Adhesive joint deformation diagram

Stretching of a belt joint generates shear stresses in an adhesive joint, their distribution along a joint (Research Project, 2004 and 2012), is shown in Figure 5.

As a result of these stresses, the ply adjacent to the joint undergoes an increase of stresses, which results in the breaking of the belt in the joint at a relatively lower stress than breaking of a continuous stretch of the belt. Experimental studies have shown that if one ply is cut in a 4-ply belt, the strength of such a belt will be lower by about 10% than the strength of the same belt with the cut ply removed before stretching (Research Project, 2004 and 2012). The belt strength drop is also influenced by the ply modulus of elasticity variability (Research Project, 2004). This is evident also when joining belts with differing strength properties.

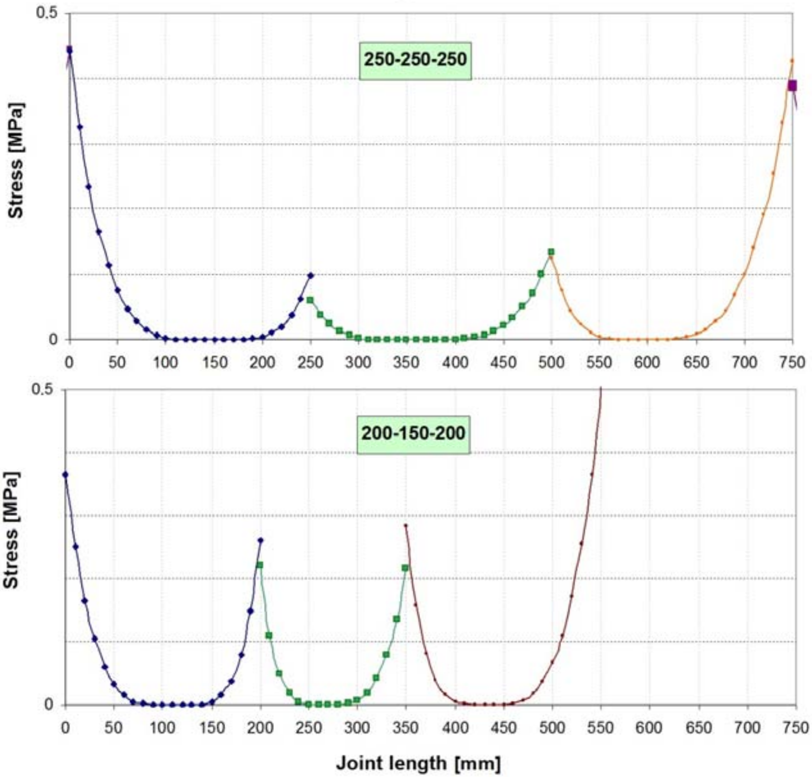

Fig. 5. Shear stress distribution in an adhesive joint of an EP 1000/4 belt with a load intensity equal to 15% of the belt strength. Lengths of tiers: (250-250-250) mm and (200-150-200) mm

Tests of the impact of the length of individual joint tiers on the stress intensity in an adhesive joint (Research Project, 2012) showed that reducing the length of outermost tiers by 20% does not affect the stress intensity, reducing the length of the middle tier by 40% slightly increases the intensity of stresses in that tier's joint, but they are still substantially lower than stresses in the outermost tiers, with simultaneously increased length of these tiers from about 60% to about 80%. The impact of tier length on the intensity and distribution of stresses in an adhesive joint is illustrated in the example of an EP 1000/4 belt joint. the first diagram shown in Figure 5 represents stresses in a typical joint with a length of 3×250 mm = 750 mm. As can be seen there is a a very heterogeneous stress distribution – high stresses at the external contact points and low stresses at the internal ones. At the same time, there are visible large areas which do not participate in load transfer. The second diagram shown in Figure 5 represents the stress distribution in an adhesive joint in which the middle tier length has been reduced to 150 mm, and the outer ones to 200 mm. The joint shortened by 200 mm in a 200+150+200 = 550 mm configuration is characterised by a more even stress distribution. Stresses at the external contact points do not differ from those in standard joints (Fig. 5) and the areas not transferring stress are decreased.

EXAMPLES OF MANUFACTURING DEFECTS

From among all the joints tested by the LTT within the last few years, 60 of those analysed displayed lower than expected strength. The percentage share of each reason for reduced strength is shown in Figure 6 (Komander, 2010).

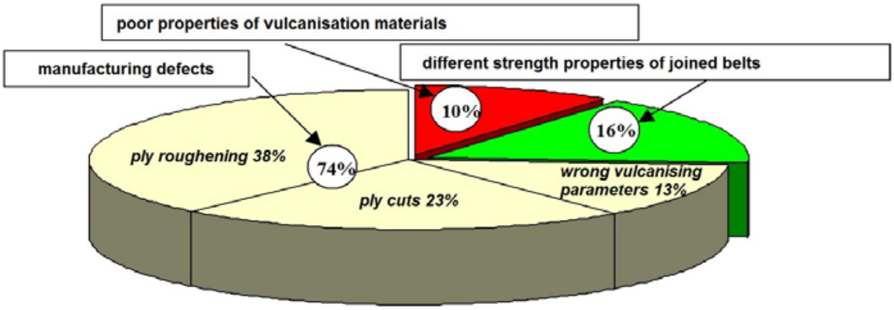

Fig. 6. Classification of the causes of reduced joint strength (Komander, 2010).

Included among the manufacturing defects in joints there were: ply roughening, ply cutting and improper vulcanisation methods [9]. The ply roughening defect caused damage to the structure of the plies, which resulted in reducing their strength. This defect occurs mostly during cleaning of friction rubber plies. Ply cutting occurring during joint seating occurs mostly at joint contact points, which increases stress concentrations in those locations. The above defects reduce joint strength by about 30%. Whereas improper vulcanisation methods are most often inadequate vulcanisation pressure, manifesting in rubber porosity, or incorrect vulcanisation temperature. Within the group of belts with differing strength properties two types can be distinguished:

- belt joints with an equal number of plies and identical strength, but different elongations,
- belt joints with different strength properties and a different number of plies.

An example of a joint of the first type could be joining a polyester-polyamide belt (EP) with a polyamide belt. Testing the tensile strength of such a joint, it is found that failure occurs in two stages: first, the EP belt plies break, followed by those of the polyamide belt. A similar breaking pattern is shown by joints of the second type. The average strength of this type of joints reaches about 65% of the required value (Komander, 2010).

SUMMARY

The strength of conveyor belt joints determines the strength of the entire belt loop on a conveyor. Strength loss within a properly made joint, depending on the number of plies, may vary from 30% to 45%. If a joint is faulty or belts with varying strength properties are joined, the additional weakening of the joint could reduce its strength by up to several dozen per cent and lead to the belt loop suddenly breaking. The strongest joints will be those between belts with the same strength properties and made without damaging the ply fabric. In a properly made joint a rupture is located at the contact point of the first or last tier. Any other breaking pattern could indicate the presence of defects.

On the basis of tests conducted at the LTT, it was determined that the length of hot-vulcanised tiers can be reduced, and the middle tiers in a joint can be shorter than external joints, without compromising the strength and durability of the joint (Komander et al., 2012; Research Project, 2012).

Presently at the LTT laboratory tests are being carried out on multi-ply joints made using the cold gluing method under research project No. PBS3/A2/17/2015. The fundamental goal of the project is to reduce the failure frequency of joints made by cold gluing, increase their operational durability and lower their cost of manufacture. The planned goal will be achieved by identifying, through research, those properties of conveyor belts and materials used for joining them, which pose a significant impact on the distribution of stresses in adhesive joints and on their fatigue life. In order to achieve the above objectives, joints will be made in conveyor belting using adhesives with various strength properties. These joints will then be subjected to testing to determine tensile strength, stress distribution and fatigue life within the joint.

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