OPTIMISATION OF THE VULCANISATION PROCESS FOR SPLICING STEEL CORD CONVEYOR BELTS USING A NEW HEATING METHOD

Lennart Schulz[1], Ludger Overmeyer[1] and Thomas Ziller[2]

[1]Leibniz Universität Hannover[2], NILOS GmbH & Co. KG

1. INTRODUCTION

Belt conveyors are used to enable high flows of bulk materials. The use of steel cord conveyor belts is appropriate where goods have to be transported over long sections or there are great differences in altitude. However, due to handling and transport restrictions, only limited segment lengths of these belts are produced. The individual segments are then spliced on site in a time consuming operation. The splicing process includes preparation and implementation of hot vulcanisation using special vulcanising devices. Hot plates positioned above and underneath the conveyor belt splice apply heat and pressure simultaneously to the splice. The combined heating method for hot vulcanisation of steel cord conveyor belts described below uses the steel cords, which are embedded in the conveyor belt to act as tension members, as an additional source of heat. In this way, the duration of the vulcanisation process can be substantially reduced, while delivering the same splice strength.

2. STATE OF THE ART OF DEVICES FOR THE HOT VULCANISATION OF CONVEYOR BELT SPLICES

As well as personnel, tools, materials and supplies, suitable vulcanising devices are vital for a hot vulcanised conveyor belt splice. Together with the type of construction, these devices are classified according to their temperature and pressure application. In addition to modular vulcanising devices that can be taken apart and are based on cross beams, a fully integrated compact design is also used. In most cases, heating coils or ceramic Positive Temperature Coefficient (PTC) heating elements are built into the pressure plate of the vulcanising presses to apply the required heat. To exert the necessary pressure, air-filled or water-filled pressure pads are frequently used. As shown in Figure 1, the pressure pad is integrated in a sandwich-type structure between the pressure equalising plate and the heating plate (Westphal, 1964. Ziller, 2010).

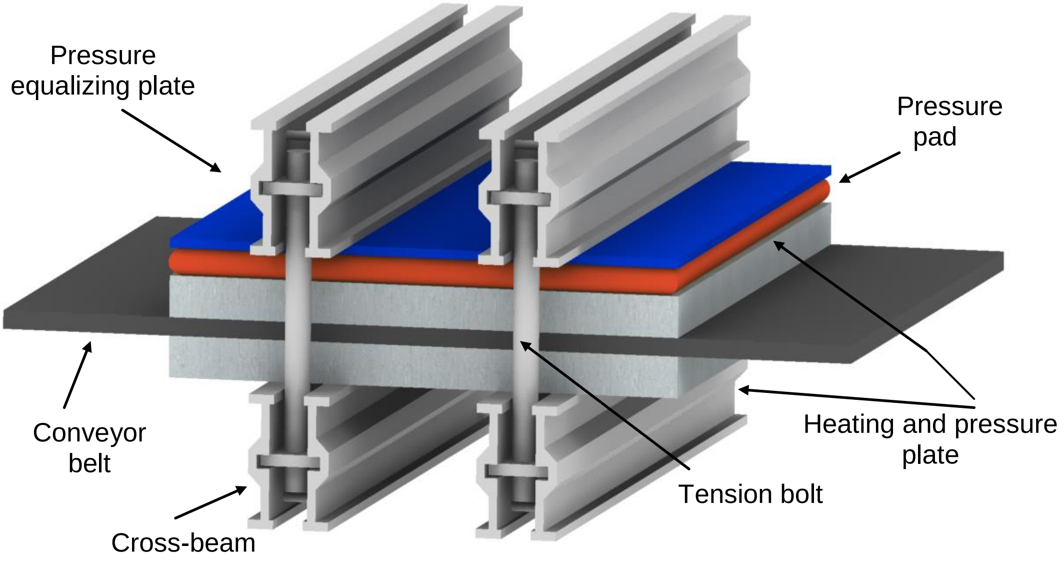


Figure 1. Pressure pad in a cross beam design vulcanising device

Another option is the use of hydraulic cylinders to generate pressure. They are inserted into the cross beams of the vulcanising device at equal distances and hydraulic fluid is supplied to them via a parallel circuit.

Irrespective of the type of construction and temperature and pressure application, the conveyor belt vulcanisation process and their splices is shown in Figure 2 (Ziller, 2010).

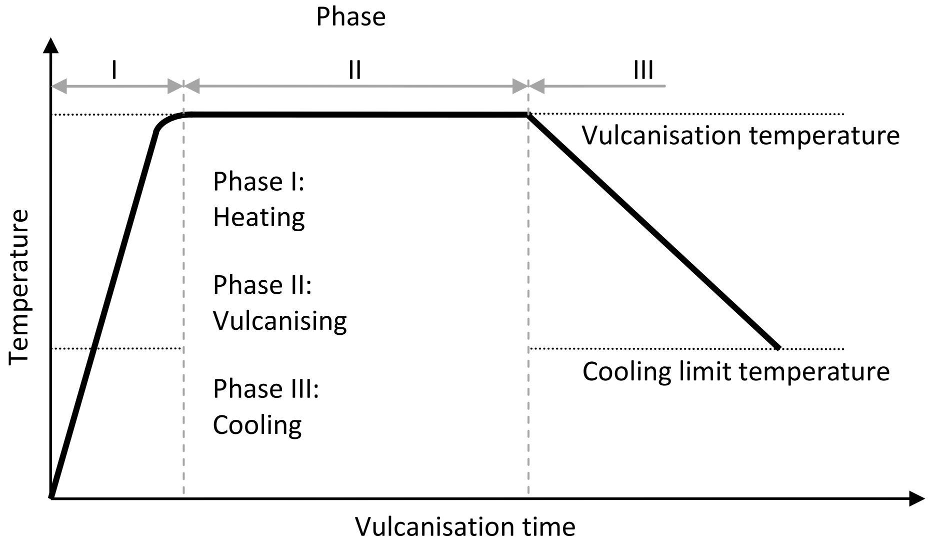


Figure 2. Schematic diagram of the vulcanisation process of conveyor belts and their splices
(after Ziller, 2010)

This idealised vulcanisation process is in reality subjected to major inhomogeneity's due to the thickness of the conveyor belt splice and the thermal properties of the elastomer, particularly in phases I and III. The low thermal conductivity and the high thermal capacity of the elastomer show the complexity of these thermally dynamic phases I and III. (Röthemeyer, 2006).

In the area in contact with the vulcanising device heating plates, the cover plate material has already been heated by the start of phase I and hence also already vulcanised, while the core of the conveyor belt splice is still at the starting temperature. The inhomogeneous heating of the conveyor belt splice in phase I results in an unevenly distributed state of cure in phase II. This effect is not new, it is seen in the production of new belts and occurs even under optimal conditions. According to Engst (1993), the state of cure curve over the conveyor belt cross-section shown in Figure 3 adjusts in a conveyor belt (type ST 4500) with a cover plate ratio of 16/8 after 31.5 minutes in phase II.

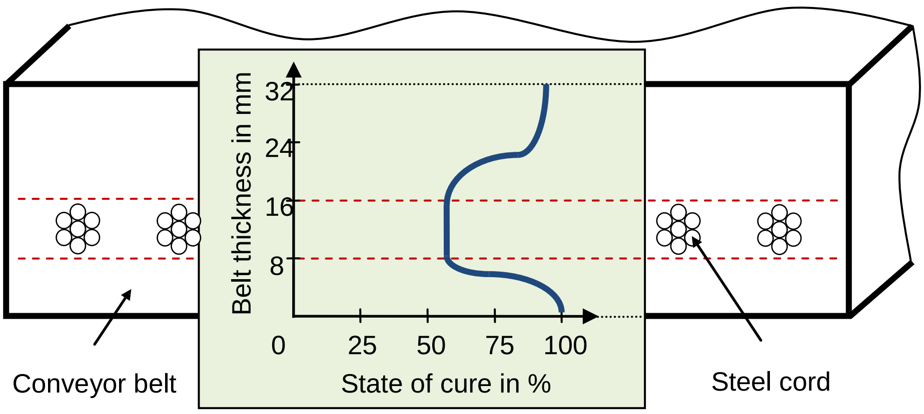
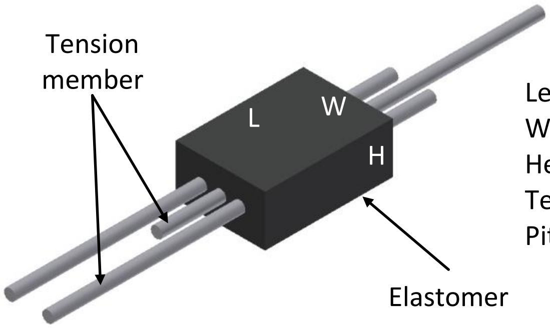


Figure 3. Local curve of the state of cure in the conveyor belt after 31.5 minutes in phase II
(After Engst, 1993)

The cover plate in direct contact with the heating plates of the vulcanising device reaches a state of cure of 100% after 31.5 minutes, while the state of cure of the core material around the steel cords is about 55%. Different vulcanising presses are used to splice conveyor belts and the splices are subject to this effect which is based on physical principles. Location related influences also affect the splice by increasing the inhomogeneity's shown. (Ziller, 2010).

3. DEVELOPMENT OF A COMBINED HEATING METHOD FOR THE VULCANISATION OF SPLICES FOR STEEL CORD CONVEYOR BELTS

The technical parameters governing the vulcanisation of splices of steel cord conveyor belts indicate the complexity of the procedure. The decisive factor is in particular, the inhomogeneous heat distribution over the cross-section of the conveyor belt splice due to the limiting thermal properties of the elastomer. Therefore, an additive heat input into the core of a conveyor belt splice presents potential for optimisation as it enables homogenisation of the heat distribution over the cross-section of the conveyor belt splice. A concept for additive heat input into the core of the conveyor belt splice based on inductive heating of the steel cords was described by Schulz, Overmeyer and Ziller (2011). Such a heat source installed in addition to the heating plates takes into account the thermal properties of the elastomer. It has been shown that, for example, in a steel cord, diameter of 9.2 mm, the heated surface in direct contact with the elastomer can be enlarged by about 62% by using the steel cords as an additional heat source.



Length L	100 mm
Width W	70 mm
Height H	40 mm
Tension member diameter	10 mm
Pitch	20 mm

Figure 4. Three-cord belt sample examined in theory and in experiments
(After Keller, 2001)

In-depth theoretical and experimental examinations are required to enable an assessment of the effects of additive heat input. This is undertaken using three-cord belt samples as shown in Figure 4. The first period of experiments were carried out on cylindrical tension members which had been treated with a cement to create adhesion with the elastomer.

3.1 THEORETICAL EXAMINATION OF HEAT DISTRIBUTION IN THREE-CORD BELT SAMPLES

A calculation method was developed by the Institute of Transport and Automation Technology (ITA) and applied to investigate the three-cord belt samples described above. This initially examined the theory of temperature distribution in the samples during the vulcanisation process (Schulz, Overmeyer, Ziller, 2012). The effects of this additive heating on the duration of phases I to III can be shown by means of the calculations. The theoretical studies for different heating methods focused on the temperature of the strength-relevant core layer shown in Figure 5, and the critical temperature zone of a conveyor belt splice arising during the vulcanisation process.

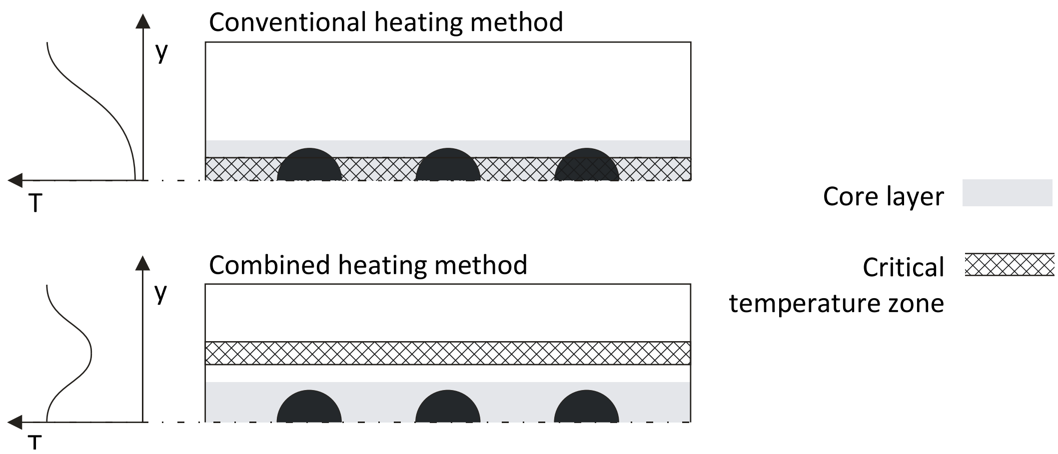


Figure 5. Qualitative temperature distribution in the cross-section of the three-cord belt sample in phase I for different heating methods

In the conventional heating method, the critical temperature zone lies within the core layer, but it is outside for the combined heating method. Thus the influence of the critical temperature zone on the core layer is reduced. Moreover, the necessary adhesion between steel cord and elastomer can build up immediately at the start of phase I and does not depend on the heat application by the conventional heating system. The design of the inductive heating unit ensures that only the cords inside the splice are heated directly, thus there is no effect on cords outside of the splicing area. There are, obviously, some thermal effects on the belt outside the splicing area in both methods.

The advantages of a combined heating method are reflected in the time curve of the difference between minimum and maximum temperature in the three-cord belt sample (Figure 6). Assuming an ideal heat source characteristic, which is the rectangular function of temperature increase, the differential temperature curve of the combined heating method shows significantly more homogeneous heating compared to the conventional method. After only ten minutes at a heat source temperature of 145°C, the differential temperature drops to below 20°C, while the temperature difference for the conventional method remains at 90°C.

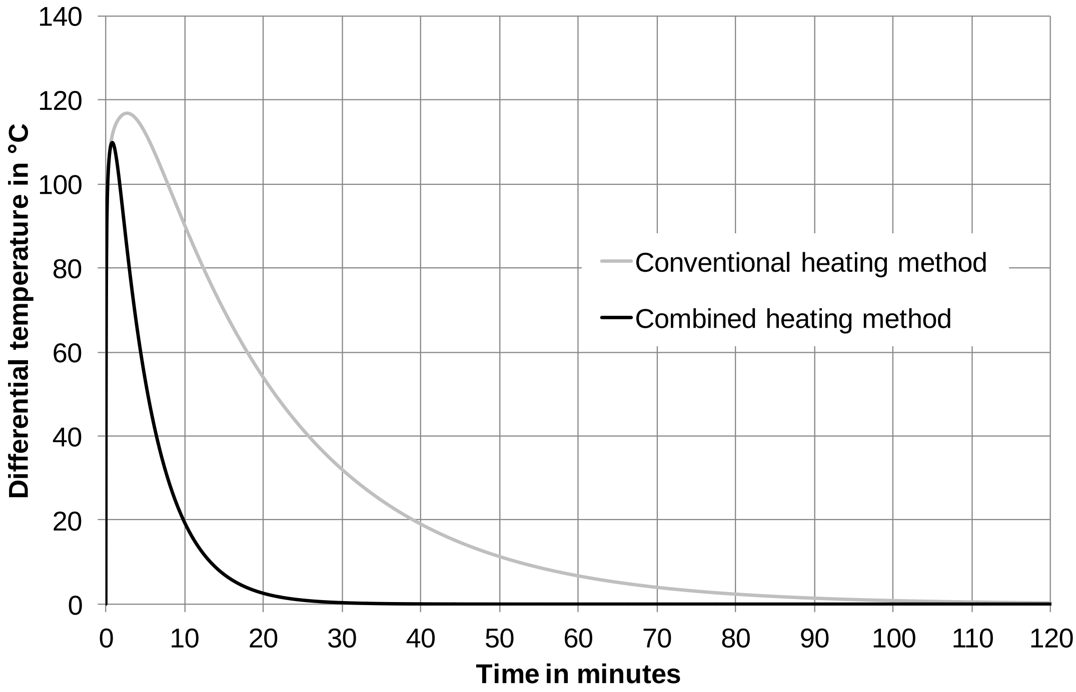


Figure 6. Theoretical curve of the difference between minimum and maximum temperature in a three-cord belt sample for different heating methods with ideal heat source characteristics

3.2 EXPERIMENTAL EXAMINATIONS OF THE HEAT DISTRIBUTION IN THREE-CORD BELT SAMPLES

In principle, inductive and conductive methods can be used to examine an additional heat input into the core of a conveyor belt splice under laboratory conditions. The inductive method requires a relatively high equipment expenditure. The same thermal effect can be achieved with less expenditure with the conductive method in which a direct current is fed into the tension members. Therefore this method was used. The respective tests were carried out on three-cord belt samples of the type described above. The direct current was fed into the tension members via terminals. The temperature inside the core layers of the three-cord belt samples was measured during the vulcanisation process by means of thermocouples. In addition, the heating characteristics of the vulcanising device were recorded and then used as a basis for the theoretical simulation of the core layer temperature curve for the combined heating method.

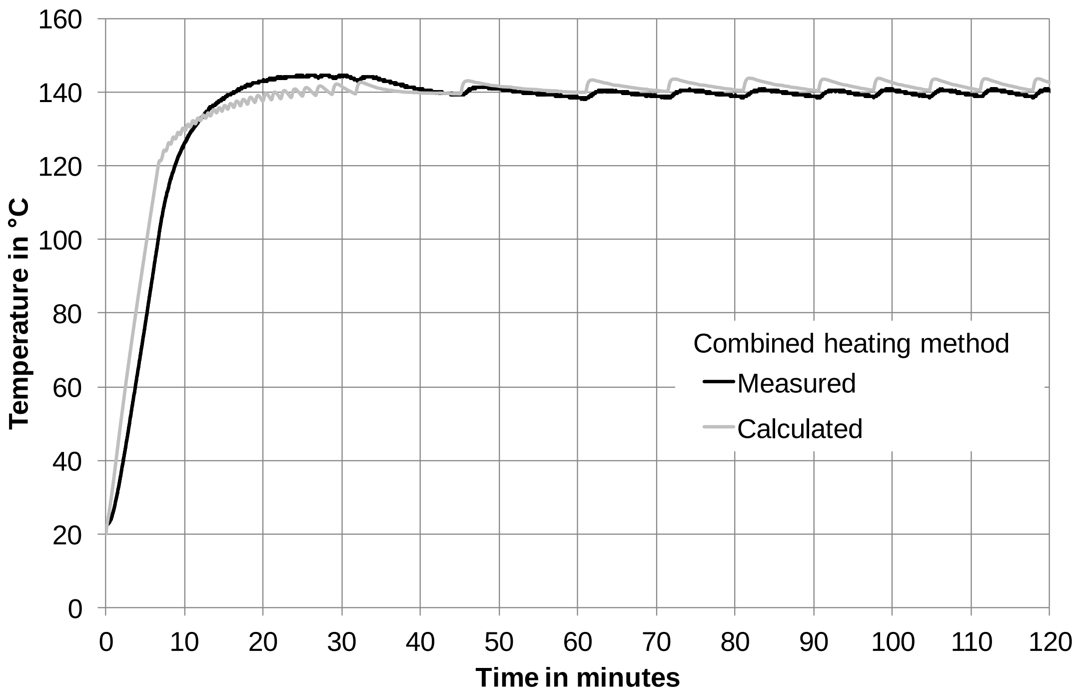


Figure 7. Theoretical and experimental temperature in the core layer of a three-cord belt sample for the combined heating method

As shown in Figure 7, the temperature curve in the core layer can be precisely simulated using the calculation method developed at the ITA. Hence, the applicability of the calculation method in practice is demonstrated.

4. EXPERIMENTAL EXAMINATIONS OF THE STRENGTH OF THREE-CORD BELT SAMPLES

In these experiments, the static and dynamic strength of three-cord belt samples using both the conventional and the combined heating method was investigated. The same vulcanisation temperature of 145°C was applied in both heating methods, the only difference being that it was reached using different heating characteristics. Accordingly, the results only show the effects of a different heating phase (phase I). Phases II and III were not changed.

Conventional heating method

In the conventional heating method, the three-cord belt samples are vulcanised by means of the heating plates arranged above and underneath the samples. Additional heat input does not take place.

Combined heating method

Various methods are feasible for the combined heating method and were thoroughly explored in the research project. However, the subject matter of this paper is exclusively the method described below in which the heating plates of the vulcanising device are operated with the same heating characteristics as the conventional heating method. In addition, the tension members in the core of the three-cord belt sample are heated to the vulcanisation temperature of 145°C within a defined period of time. As a consequence, different temperature gradients are dependent on the respective defined target heating time. A target heating time of 300 seconds was defined for the tests described here. This time corresponds to about 10% of the duration of phase I when using the conventional heating method.

4.1 STATIC TESTS

The static tests of the three-cord belt samples were conducted according to DIN 7623. The aim of the tests was to determine the influence of the two different heating methods on the static pull-out strength of a three-cord belt sample of the design described in Section 3. Conforming to DIN 7623, the three-cord belt samples were stressed until fracture by a movement speed of the clamping device of 100 ±10 mm/min (Figure 8, left). (DIN EN ISO 7623, 1997).

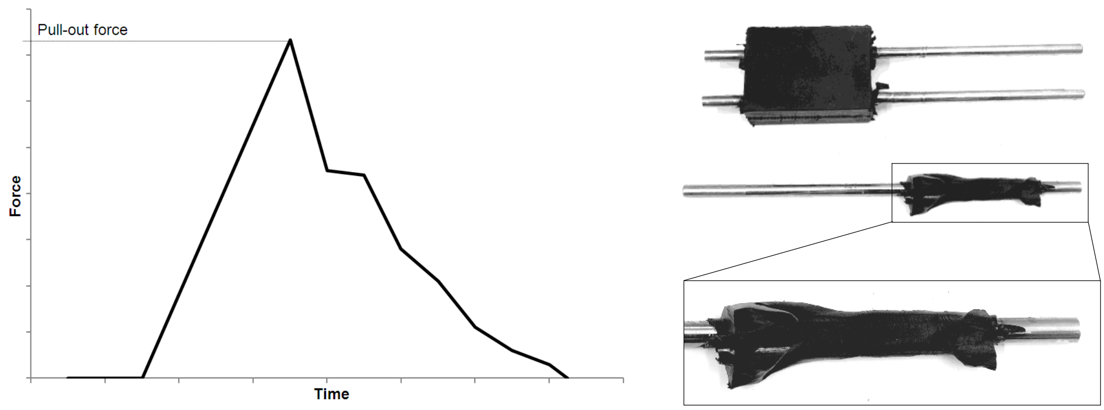


Figure 8. Schematic diagram of the force curve for the static pull-out strength of three-cord belt samples (left). Example of fracture pattern of a three-cord belt sample (right)

Five test pieces per heating method were examined. In all test pieces, the fracture was in the form of a purely structural interruption in the elastomer (Figure 8, right). Table 1 shows the results including their relative deviations compared to the conventional heating method.

Heating method	Mean of static pull-out strength in %	Largest positive deviation of static pull-out strength from mean in %	Largest negative deviation of static pull-out strength from mean in %
Conventional	100.0	+4.4	-0.1
Combined	102.8	+9.2	-3.7

Table 1. Test results of the static pull-out strength of three-cord belt samples compared to the conventional heating method

Table 1 shows the results of the two heating methods and the deviations from the mean of the static pull-out strength of the conventional heating method. The results do not show a significant influence of the combined heating method in phase I on the pull-out strength of the three-cord belt samples compared to the conventional heating method. The static strength is neither significantly increased nor decreased.

4.2 DYNAMIC TESTS

The dynamic tests of the three-cord belt samples were carried out following DIN 22110-3 and AS 1333. The aim of the tests was to determine the influence of the two different heating methods on the finite-life fatigue strength of a three-cord belt sample of the design described in Section 3. Conforming to DIN 22110-3 and AS 1333, the three-cord belt samples were subjected to cyclic loads which are described by a highest load, a lowest load, a ramp rise or ramp fall time and a holding time (Figure 9, left). The lowest load was 4.0 kN in all tests and kept constant at each load cycle for a period of 1 second. The periods of force increase to highest load or force decrease to lowest load were 2 seconds at each load cycle, so that the resulting load cycle period was 5 seconds. The highest load could be chosen freely. The duration of a test depended on the number of load cycles passed until fracture of the three-cord belt sample. (DIN 22110-3, 2007. AS 1333, 1994).

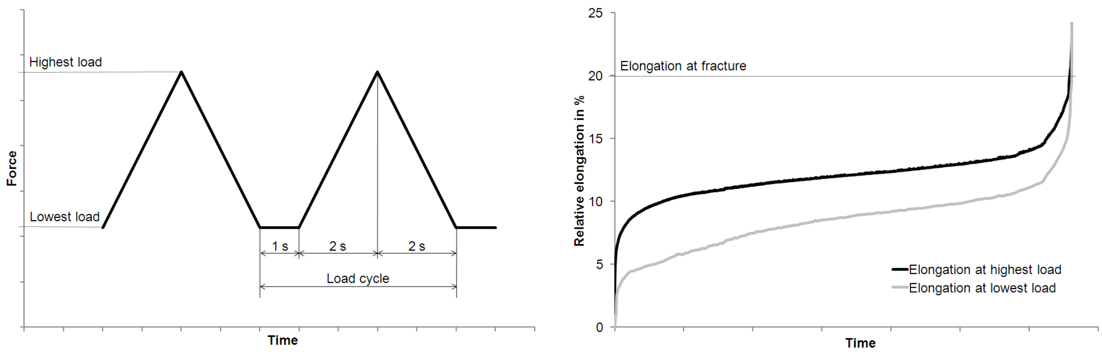


Figure 9. Schematic diagram of the test load curve for the dynamic test of the three-cord belt samples (left). Example of elongation behaviour of a three-cord belt sample (right)

Figure 9, right, shows an example of elongation behaviour of a three-cord belt sample in a dynamic test. The change of elongation over time, both at the highest load and at the lowest load, is present for the entire duration from the start of the test and the end, due to the fracture of the test piece. The figure shows that an elongation of about 20% occurs when the sample fails under the highest load. The elongation behavior shown is accurately determined by the properties of the elastomer and the design of the three-cord belt sample examined. The elongation behaviour allows further conclusions as to the formation of the sample's dynamic pull-out strength.

Four three-cord belt samples were examined for each heating method. In all test pieces, the fracture was in the form of a purely structural interruption in the elastomer. By combining the test results, a finite-life fatigue strength curve was recorded for the test pieces for both heating methods. From these curves, a relative reference fatigue strength is calculated for a pre-determined number of load cycles of 10 000. This strength value is purposely not shown as an absolute value but as a relative value by relating it to the mean of the static pull-out strength of the three-cord belt samples tested with the conventional heating method (Table 2).

Heating method	Relative reference fatigue strength in %
Conventional	38
Combined	39

Table 2. Relative reference fatigue strength of the examined three-cord belt samples for different heating methods

According to Table 2, the test results do not show that the heating method has a significant influence on the relative reference fatigue strength. The results of the tests are nearly identical for both heating methods. This means that the dynamic strength is neither significantly increased nor decreased.

4.3 ECONOMIC IMPORTANCE OF THE TEST RESULTS

The aim of the following discussion is to determine the effects of the different heating methods on the duration of the heating phase (phase I). To this end, the temperatures inside the core layers of the three-cord belt samples were measured and recorded during the entire vulcanisation process. Figure 10 shows examples of temperature curves for both heating methods and displays the different heating characteristics. In the conventional heating method, the temperature inside the core layer rises slowly and approaches the pre-defined vulcanisation temperature of 145°C asymptotically. The combined heating method is characterised by the fact that the tension members are additionally heated to the vulcanisation temperature within a fixed period. Figure 10 shows this characteristic at the start of phase I. The core layer follows, with a delay, the temperature of the tension member given by the heating method. Once the tension member has reached the required vulcanisation temperature of 145°C, the temperature is kept constant by the regulating algorithm of the combined heating method. This explains the more gradual rise of the temperature in the core layer that occurs after about five minutes, after which the temperature approaches the specified vulcanisation temperature, also asymptotically.

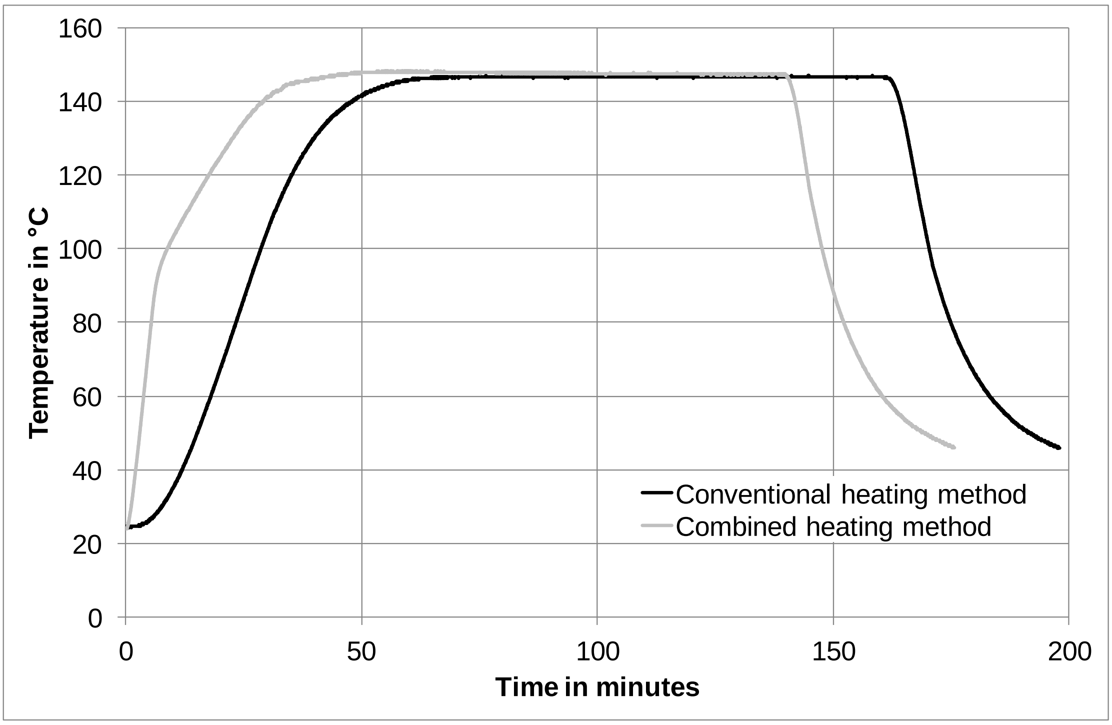


Figure 10. Temperature inside the core layer of a three-cord belt sample during the vulcanisation process for different heating methods

With regard to the duration of the heating process until the defined vulcanisation temperature of 145°C is reached, the heating methods examined show substantial differences. Using the combined heating method can reduce the duration of phase I by up to 45% compared to the conventional heating method. This percentage is calculated and based on the conventional heat-up process described.

5. SUMMARY AND OUTLOOK

A combined heating method was developed to optimise the vulcanisation process of steel cord conveyor belt splices. The method uses the tension members embedded in the steel cord conveyor belt as an additional heat source. Both theoretical and experimental investigations were carried out to assess the effectiveness of the new method. In the context of the theoretical investigations, a calculation method was developed to enable an analysis of the heat distribution in steel cord conveyor belt splices during the vulcanisation process. A three-cord belt sample was used as reference geometry. The applicability of the method was demonstrated by comparing temperature curves obtained by theoretical investigations and experiments. Hence, the effects of the combined heating method can be compared by means of calculations to the conventional heating method. It was shown that the temperature differences during the vulcanisation process inside a three-cord belt sample can be substantially reduced by the combined heating method. Subsequently, static and dynamic strength assessments were carried out on three-cord belt samples. In the studies, test pieces produced with the conventional and the combined heating method were compared to each other in terms of strength. Both the static and the dynamic strength values of the three-cord belt samples showed just marginal differences for the two heating methods. However, a substantial difference was found in respect of the duration of the heating process (phase I). The use of the combined heating method can reduce the heating process by up to 45% compared to the conventional heating method.

Since the investigations for the modified heating process (phase I) already show a considerable potential for time savings, it is intended to address the impact of a modified vulcanisation phase (phase II) in future research. This will also focus on the strength of the vulcanised three-cord belt samples and the duration of the vulcanisation phase. Since the conductive heating method that made it possible to perform the first period of investigations can be implemented only in a laboratory environment, further tests are necessary using an inductive heating method. Currently, no full scale splices have been done, but investigations on a small scale are still being conducted. It thus becomes a prerequisite to develop and construct an appropriate vulcanising device. It will then be possible to compare the conductive and the inductive heating methods, and to verify the practical application of the new combined (conventional and inductive) heating method for vulcanising devices for the splicing of steel cord conveyor belts.

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REFERENCES

1 Westphal, H. (1964). *Handbuch der Fördergurte*. Leipzig. Deutscher Verlag für Grundstoffindustrie.

2 Ziller, T. and Hartlieb, P. (2010). *Fördergurte in der Praxis*. Essen. VGE Verlag.

3 Röthemeyer, F. and Sommer, F. (2006). *Kautschuk-Technologie*. München. Hanser Verlag.

4 Engst, W. (1993). Herstellungsverfahren und Aspekte des Vulkanisationsprozesses von Fördergurten. *Kautschuk Gummi Kunststoffe 46*. No. 2. 129-138.

5 Schulz, L. Overmeyer, L. and Ziller, T. (2011). Novel Splice Vulcanizing Presses with Optimized Heating and Pressure Characteristics. *Bulk Solids Handling, Mining Special 31.* No. 4. 216-221. Würzburg. Vogel Business Media.

6 Keller, M. (2001). *Zur Optimierung hochfester Stahlseilgurtverbindungen*. Dissertation Universität Hannover.

7 Schulz, L. Overmeyer, L. and Ziller, T. (2012). Ein neues Verfahren zur Heißvulkanisation von Verbindungen für Stahlseilfördergurte. *Fachtagung Schüttgut - fördern und lagern, 9*. 61-72. Fulda. VDI Wissensforum.

8 DIN Deutsches Institut für Normung e. V. (1997). *DIN EN ISO 7623:1997 Steel cord conveyor belts - Cord-to-coating bond test - Initial test and after thermal treatment*. Berlin. Beuth Verlag GmbH.

9 DIN Deutsches Institut für Normung e. V. (2007). *DIN 22110-3:2007 Testing methods for conveyor belt joints - Part 3: Determination of time strength for conveyor belt joints (dynamical testing method)*. Berlin. Beuth Verlag GmbH.

10 Standards Association of Australia (1994). *AS 1333:1994 Conveyor Belting of Elastomeric and Steel Cord Construction.* Sydney. Standards Australia.

ABOUT THE AUTHORS

LENNART SCHULZ

Diploma (mechanical engineering), Fachhochschule Lippe und Höxter, 2008.
Research associate at Institut für Transport- und Automatisierungstechnik (ITA), Leibniz Universität Hannover, since 2008. Group manager of the working group "Transporttechnik" (Transportation Technology) at Institut für Transport- und Automatisierungstechnik (ITA), Leibniz Universität Hannover, since 2011.

Dipl.-Ing. (FH) Lennart Schulz
Leibniz Universität Hannover
Institut für Transport- und Automatisierungstechnik (ITA)
An der Universität 2
30823 Garbsen, Germany
Tel: +49 (0)511 762-18160
E-mail: lennart.schulz@ita.uni-hannover.de

LUDGER OVERMEYER

Diploma (electrical engineering), Universität Hannover, 1991.
Doctorate (mechanical engineering), Universität Hannover, 1996.
Project manager, division manager, head of research and development, Mühlbauer AG, Roding, 1997-2001.
Professor (mechanical engineering), Institut für Transport- und Automatisierungstechnik (ITA), Universität Hannover, since 2001.

Prof. Dr.-Ing. Ludger Overmeyer
Leibniz Universität Hannover
Institut für Transport- und Automatisierungstechnik (ITA)
An der Universität 2
30823 Garbsen, Germany
Tel.: +49 (0)511 762-3524
E-mail: ludger.overmeyer@ita.uni-hannover.de

THOMAS ZILLER

Diploma (mechanical engineering), Rheinisch Westfälische Hochschule Aachen, 1982.
Assistant to the management, Montan-Forschung Dr. Hans Ziller, Hilden, 1982.
Personally liable partner and take-over of the management, Montan-Forschung Dr. Hans Ziller and Kroll und Ziller KG, Hilden, 1986.
Managing director, Ziller-Beteiligungs GmbH, Hilden, 1998.

Dipl.-Ing. Thomas Ziller
NILOS GmbH & Co. KG
Reisholzstraße 15
40721 Hilden, Germany
Tel.: +49 (0)2103 951-0
E-mail: thomas.ziller@nilos.de ..