Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 100 (2015) 1160 – 1166

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Vulcanization of Rubber Conveyor Belts with Metallic Insertion Using Ultrasounds

Dan Dobrotă*

Engineering Faculty, University "Constantin Brâncuşi" of Târgu-Jiu, 201141, România

Abstract

For increasing the life of conveyor belts, it requires a vulcanization joint of them, so that, in the joint area, physical and mechanical characteristics must be the same or very close to the rest of the conveyor belt. Conveyor belts with rubber matrix and embedded metallic insertions are working in very difficult operating conditions and thus their jointing require to take place in optimal conditions. Researches have taken into consideration the type of ATRBZ rubber conveyor belts reinforced with embedded metallic insertions. To observe the effect of applying ultrasound on vulcanization process, there were considered two distinct processes, namely one in which ultrasonic energy is not used, and one in which the process is activated ultrasonic, with frequencies in the range of 17-19 / kHz. Applying ultrasound showed a vulcanized joint of conveyor belts with embedded metallic insertions have superior characteristics in comparison with those obtained when not using ultrasound.

Keywords: metallic insertions; conveyor belts; vulcanization; ultrasounds

1. Introduction

Rubber products, used in different industry areas, can be manufactured in requested sizes. These products can have bigger or smaller dimensions, which determine the uses of vulcanization as a method for jointing products to obtain desired dimensions. In this category of products are included conveyor belts for raw materials and materials, when the distances to transport are bigger than the usual fabrication length of conveyor belts [1].

Also, conveyor belts of special importance, which must have high mechanical properties, have in their structure

* Corresponding author. Tel.: +40-0253-237252; fax: +40-0253-214462.
E-mail address: ddan@utgjiu.ro

doi:10.1016/j.proeng.2015.01.479

different insertions (textile, metallic) and their properties are based on adhesions rubber-insertion. These conveyor belts are used for equipping large capacity conveyors or those working under heavy conditions (sharp slope, high speed, with big lengths to transport), where is requesting a very good breaking strength, special flexibility and high reliability [2]. Rubber industry often faces the problem of wear of rubber parts. The tire tread is the part of conveyor belts which is directly involved in the transfer of driving power. The wear of conveyor belts is characterised by abrasion [3]. The issue of wear represents a very important role in the functionality of most products. The description of the wear process for very heavily strained rubber products, for instance off-road tire treads, conveyor belts for stone transport etc., is very essential. Sharp edges of stones and terrain roughness gradually cut (chip) off rubber parts. This wear considerably damages separate parts of the product and destroy it. [4]. For an increasing lifetime of conveyor belts is necessary a vulcanized joint, such that in bonding areas the mechanical characteristics being the same or close to those in the rest and to obtain the homogeneity of the whole conveyor belt. The chemical cross-linking or rubber vulcanization is normally induced by the effect of heating after processing with the presence of a curing agent [5].

Vulcanization kinetics of natural rubber was influenced by vulcanization temperature, rubber mixing process, ingredients mixing sequence in rubber compounding, and the type of carbon black. Higher vulcanization temperature provided faster reaction rate of vulcanization [6].

Rubber adhesive using in manufacturing of laminated structures partially dissolves a contact surface of elastomeric (with initial thickness he) during vulcanization, forming a transitional layer of hc thickness with mechanical characteristics different from the characteristics of the adhesive and elastomeric [7]. In the past, traditional rubber was widely used as a flexible environment. Nowadays it has been substituted in most cases by polyurethane, which has superior physical properties and can better withstand the cyclic workloads [8].

Generally, vulcanization joints of different rubber products, and especially conveyor belts, generates in bonding areas, mechanical characteristics lower than the rest of the product, the fact that causes a decrease of product lifetime. In this regard, in this paper is aimed finding of a technical solution which permits homogenization of proprieties both in bonding area as in the rest of the product [9].

2. Materials and methods

Any vulcanization process of a rubber product is made today by adjustment of three technological parameters, that are: vulcanization time, vulcanization temperature and holding the pressure at the ends. Adjusting the time of vulcanization of rubber products, in order to join them, is done according to the thickness of the rubber in jointing area. To adjust the temperature of vulcanization is investigated the type of the rubber used in the vulcanization process, and the holding pressure is determined by the thickness of rubber and its structure [10].

The three previously mentioned parameters can take different values depending on a particular type of rubber product, and if adjusting these parameters is not to the optimal values, then the results regarding the characteristics of the joints are not appropriate. Poor results are mainly determined due to the presence in the joint of a highly porous material, and this causes a decrease in the mechanical characteristics of the joints.

Reducing the porosity of the jointing area can be achieved by proper adjustment of the three technological parameters at optimal values, and by using ultrasonic energy introduced in the joint [11]. Application of ultrasonic energy in the joint area of vulcanized rubber products is based on the effect that this has on solid medium. The use of ultrasonic energy can affect both the structure and the mechanical characteristics of the material and its physical and chemical properties of the composite material made of rubber and metallic insertion.

The products of ultrasonic process exhibit the same properties as those that are vulcanized by using conventional process. However, the ultrasonic vulcanization process demonstrates many advantages over the traditional vulcanization methods such as high production rate, energy saving, uniform cure, etc. Energy generated due to phase difference between strain and stress, and sonochemical reaction within the compound are considered responsible for the vulcanization of rubber. The dynamic properties of unvulcanized natural rubber under ultrasonic frequency are obtained by means of the method of reduced variables. Also found adhesive strength of steel cord to natural rubber after ultrasonic vulcanization is much greater than thermal vulcanization. This was attributed to better degassing and microfriction at the interface. However, adhesive strength natural rubber to polyester cord in ultrasonic cure was inferior, possibly due to ultrasonic degradation fibres [12].

In the process of joining by vulcanization, temperature is one of the parameters of special importance, and in this sense, there must be considered also the thermal effect of ultrasonic waves [13]. The ultrasonic waves are absorbed more intensely in areas where dislocations occur in material and in this aspect, the use of ultrasonic waves can cause a substantial reduction in the pores of the joint [14].

Today, there are used different opinions on this phenomenon, but mainly, the researches refer to metallic materials and less to materials such as rubber or composite materials with rubber matrix [15]. Based on these mentioned facts, the use of ultrasonic energy in the rubber joining products is a novelty in the field and also the results can be used in other processes of combining different types of composite materials used in various fields.

Carrying out the experiments was conducted in two phases, namely the first phase was achieved by vulcanization without using ultrasonic energy, and in the second phase the joining by vulcanization process took place in the presence of ultrasonic energy. For the experiments, there were used general purpose conveyor belts of ATRBZ rubber, which have the armed structure with metallic insertion.

It was chosen such a conveyor belt, because it must provide a good tensile strength, great flexibility and high reliability. Also, the subject of the study, the conveyor belt is characterized by a width of 2400 / mm and a thickness of 28 / mm. To achieve joining by vulcanization is required processing end surfaces and in this respect the subject it was done, the ends processing ends, as shown in Figure 1. The rubber used to create connections between the ends of the conveyor belt was also a rubber ATRBZ type in an uncured state.

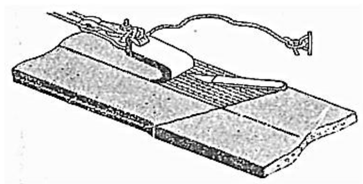

Fig. 1. Mode of processing conveyor belt ends.

3. Experimental results

For conducting experiments, there must be found the method to allow their deployment with minimal cost, shorter time, but without changing the expected results. In conducting experiments, there were followed two stages, namely:

- conducting experiments;
- analysis of experimental data obtained.

The study of a phenomenon in a particular field of activity is conducted through an analysis of the influence of various factors on this phenomenon, and this can be achieved by studying the influence of each factor on this phenomenon by keeping other factors constant. Therefore, the experimental method used was the method of factorial experiments.

To simplify the experimental research program there were used, for each influencing factor, two levels, namely the minimum level and maximum. Considering the above, the structure of experimental research program differs depending on the method adopted, namely vulcanization when combining with ultrasonic energy, case when experimental research program includes 16 experiments (2^4 - two levels for the four factors of influence: vulcanization time, vulcanization temperature, contact pressure and ultrasound frequency), Table 1, and conventional vulcanization without using ultrasonic energy experimental research program includes 8 experiences (2^3 - two levels for the three factors of influence: vulcanization time, vulcanization temperature and contact pressure).

Table 1. Program of experimental researches for vulcanization using ultrasonic energy.

Number	Pressure bar		Maintaining time / min		Temperature / ^{0}C		Ultrasound frequency kHz	
experience	340	380	60	80	130	155	17	19

1	x		x		x		x	
2	x			x	x		x	
3	x		x			x	x	
4	x			x		x	x	
5		x	x		x		x	
6		x	x			x	x	
7		x		x	x		x	
8		x		x		x	x	
9	x		x		x			x
10	x			x	x			x
11	x		x			x		x
12	x			x		x		x
13		x	x		x			x
14		x	x			x		x
15		x		x	x			x
16		x		x		x		x

Table 2. Program of experimental researches for vulcanization without ultrasonic energy.

Number experience	Pressure bar		Maintaining time min		Temperature ^{0}C	
	340	380	60	80	130	155
1	x		x		x	
2	x			x	x	
3	x		x			x
4	x			x		x
5		x	x		x	
6		x	x			x
7		x		x	x	
8		x		x		x

To conduct the joint operations by vulcanization, there were used two schemes, namely vulcanization without using ultrasonic energy, as shown in Figure 2, respectively vulcanization with the use of ultrasonic energy, as shown in Figure 3.

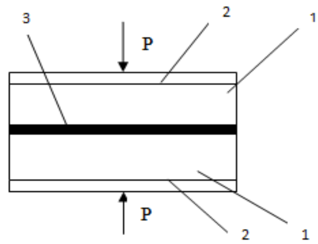

Fig. 2. The scheme of the vulcanization joining process of two conveyor belts, without ultrasonic activation: 1- conveyor belts undergoing joining process; 2- plates that have the role of providing the heat and pressure necessary in the vulcanization process; 3- ATRBZ uncured rubber used as additional material in the vulcanization joining process of conveyor belts.

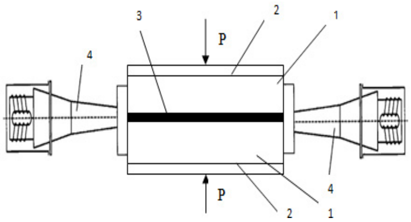

Fig. 3. The scheme of the vulcanization joining process of two conveyor belts using process intensification with the help of ultrasonic energy: 1- conveyor belts undergoing the joining process; 2- plates that have the role of providing the heat and pressure necessary in the vulcanization process; 3- ATRBZ uncured rubber used as additional material in the vulcanization joining process of conveyor belts; 4-ultraacoustic system with pad type active element.

As a result of all experiments, there was intended as the first step the identifying of any gaps (porosity) remaining in the joint. To achieve this, there was used the ultrasound analysis method because it is the only method that allows the identification of existing porosity in such material. Following this analysis, it was found that the pore volume in the case of conventional vulcanization without using ultrasound is between 8 to 10 % of total material to be vulcanized, and in the case of vulcanization activated by ultrasonic, the pore volume was less than 0,2 % and if experiments were characterized by an ultrasound frequency of 19 kHz, the pores were absent.

It is specified that the ultrasonic energy must be inserted in the joint area only at a temperature of 100 ^{0}C because above this level the presence of ultra sounds is not good. This temperature was adopted because filler material, i.e. ATRBZ rubber, begins vulcanization process over this temperature.

Also from all obtained joints was taken a sample (Figure 4), which was tensile tested on a dynamometer with the following characteristics:

- Maximum power that the device can develop 100 kN.
- Mobile clip speed is constant and has a value of 100 ± 10 mm/min.
- Dynamometer measurement error is max. 1 %.
- Maximum stroke length is 1000 mm.

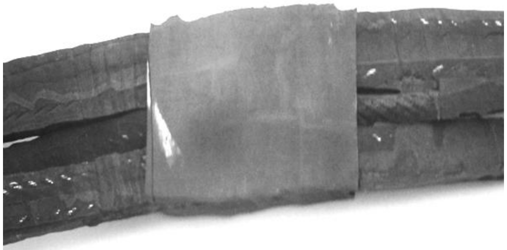

Fig. 4. Type of test-piece used in experiments.

Tensile tests were performed for 8 samples, corresponding to the eight experiments, where vulcanization was made without the use of ultrasonic energy, and for 16 samples, corresponding to the 16 experiments performed if vulcanization was made by using ultrasonic energy. The results for tensile testing samples, obtained for the vulcanization made using ultrasonic energy, are shown in Table 3, and the results obtained for tensile testing performed for samples, obtained at vulcanization without using ultrasonic energy, are presented in Table 4.

Table 3. Traction strength values in case of using ultrasonic energy.

Number experience	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Traction strength KJ/cm	711	1049	893	888	827	864	725	853	727	1062	901	893	849	872	736	862

Table 4. Traction strength values

Number experience	1	2	3	4	5	6	7	8
Traction strength KJ/cm	543	739	671	615	636	601	557	619

The analysis of data presented in Table 3 and Table 4, shows that the use of ultrasonic energy causes a substantial increase in the tensile strength of the samples, and this is mainly determined by achieving a very good homogeneity of the material in the joint and removing pore of the joint area.

This difference was noticed and by the way was done breaking tensile samples tested, namely in Figure 5 is presented the rupture of a sample obtained using conventional vulcanisation and in Figure 6 is presented the case of rupture of joint obtained by vulcanization using ultrasonic energy.

Fig. 5. Breaking of the vulcanization joined test pieces along the joining area.

Fig. 6. Breaking of vulcanization joined test pieces in the case of using ultrasonic energy.

For analysis of Figures 5 and 6 is observed that the sample rupture was performed along the joints when vulcanization was made without the use of ultrasound and when using ultrasound the sample rupture was transverse towards the junction area, which demonstrates the fact that the jointing material has the same characteristics of the material as the rest of the conveyor belt.

The results presented in Table 4 allow us to conclude that the maximum tensile strength was obtained from the sample made by adjusting the following parameters: pressure p = 340 bars, vulcanization time 60 min, vulcanization temperature 140 ^{0}C. Also from the data presented in Table 3 is seen that the best tensile strength is obtained from the sample made with the three parameters mentioned above, but also by adjusting a frequency of the ultrasonic waves at 19 kHz.

By the statistical processing of data from Tables 3 and 4 it was observed that of the four adjustable parameters at vulcanization using ultrasonic energy the greatest importance has ultrasonic wave frequency, followed by contact pressure. This can be explained by the fact that both of the parameters contribute to the elimination of pores in the joining area and to achieve homogeneity of the material.

The use of ultrasound is the latest method in the vulcanization of rubber. The use of ultrasound in the vulcanization process, in addition to the conventional process, when is used only heat, is indicated also at the polymerization of composite materials with polymer matrix. Should be taken into account that for composite materials with polymer matrix the possibility of rainnforced degradation if it is made of a material such as for example polyethylene. Using the the ultrasounds at jointing of rubber conveyor belts with metallic insertion allowed obtaining very good results because metallic materials do not degrade in the presence of ultrasounds.

Used ultrasonic waves is very interesting because polymerization, crosslinking and degradation can be carried out by changing the conditions of ultrasonic application. On the other hand, is the medium in contact is constituted of a viscoelastic material such as rubber, the ultrasonic energy is converted to heat by relaxation and frictional processes. Since, the ultrasonic waves are generated the bulk of the material, the heating is uniform and vulcanization process is very good

Conclusion

Theoretical and experimental research presented in this paper, allows finding technical solution which permits following conclusions:

- Best results in conventional vulcanization were obtained for a pressure p = 340 bars, a vulcanization time of 60 min and a vulcanization temperature of 140 ^{0}C.
- To obtain good results in activated ultrasonic vulcanization is necessary to use ultrasonic waves with a frequency of 19 kHz.

- Application of vulcanization, on conveyor belts with embedded metallic insetion, using ultrasound causes an increase in tensile strength by 30 to 40 % and a reduction in the porosity of the joint, almost to eliminate it, as seen on sample number 2 obtained from combining vulcanization with the use of ultrasound.
- The technical solution proposed can be applied in practice, with the opportunity of creating outstanding results, with an increase in adhesion between rubber and metal insertion and consequently the life of conveyor belts and a decrease in consumption of materials and energy consumption and ultimately a considerable reduction of environmental pollution.
- The results presented in the paper can be used for vulcanization joints of other products made of rubber with embedded metallic matrix or composite material of rubber and reinforcing filler metal insertion.

References

[1] D. Dobrotă, Adhesion degradation of rubber and steel insert for conveyor belts, J. of Adh. Science and Technology, 27 (2013) 125-135.
[2] Gh. Amza, D. Dobrotă, A. Semenescu, A., D. Iancului, Researches concerning the ultrasonic energy's influence over the resistance at extraction of the metallic insertion from the rubber matrix, Materiale Plastice, 45 (2008) 4 377-380.
[3] D. Manas, M. Stanek, M. Manas, M. Ovsik, V. Pata, J. Cerny, Visualization of tire tread behaviour at wear process, Proceedings of the 22nd International DAAAM Symposium, 22 (2011) 0415 – 0416.
[4] J. Cerny, K. Kyas, M. Krumal, M. Martin, D. Manas, M. Manas, M. Michal, Wear process of tires, Proceedings of the 21nd International DAAAM Symposium, 21 (2010) 1189-1190.
[5] M. Ovsik, D. Manas, M. Stanek, M. Manas, J. Cerny, M. Bendarik, A. Mizera, The chemical cross-linking or rubber vulcanization is normally induced by the effect of heating after processing with the presence of a curing agent, Proceedings of the 22nd International DAAAM Symposium, 22 (2011) 1187 – 1188.
[6] A. Hasan, R. H. Sulistyo, S. Honggokusumo, Vulcanization kinetics of natural rubber based on free sulfur determination, Indo. J. Chem., 13 (2013) 21-27.
[7] V. Gonca, S. Polukoshko, Theoretical and experimental studies of stiffness properties of laminated elastomeric structures, Proceedings of the 9th International DAAAM Baltic Conference "Industrial Engineering", 24-26th April 2014, Tallinn, ESTONIA, 342-347.
[8] J. Vilcans, T. Torims, M. Zarins, A. Ratkus, Experimental analysis of the rubber pad forming, Proceedings of the 2nd International DAAAM Symposium, 22 (2011) 0613-0614.
[9] Y. Wang, B. Su, J.Wu, Simulation and optimization of giant radial tire vulcanization process, Procedia Engineering, 31 (2012) 723-726.
[10] F. Pechacek, M. Charbulova, Ultrasound influence in hole grinding process to Al203 material, Proceedings of the 21nd International DAAAM Symposium, 21 (2010) 0295-0296.
[11] J. Matthias, W. Stark, Monitoring the vulcanization of rubber with ultrasound: Influence of material thickness and temperature, Polymer testing, 28 (2009) 901-906.
[12] H. Zeng, B. Wen, Ultrasonic vulcanization of natural rubber, Ciesc Journal, 54 (2003) 1749.
[13] M. D. Stanciu, I. Curtu, O. M. Ovidiu, A. Savin, C. Cosereanu, Evaluation of acoustic attenuation of composite wood panel through nondestructive test, Proceedings of the 22nd International DAAAM Symposium, 22 (2011) 0393-0394.
[14] Y-R. Liang, Y-L. Lu, Y-P Wu, Li-Q. Zhang, Pressure, the critical factor governing final microstructures of cured rubber/clay nanocomposites, Micromolecular rapid communications, 26 (2005) (11), 926-931.
[15] M. Entezari, N. Ghows, M. Chamsaz, Ultrasound facilitates and improves removal of Cd(II) from aqueous solution by the discarded tire rubber, J. of Hazardous Materials, 131(2006) 84-89.