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Experimental Study of Rubber Composite Quality Assessment in Terms of Electrical Conductivity and Accelerated Thermal Ageing

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Abstract **– Belt conveyors represent efficient transport systems that are used for transportation of bulk materials across all industries. Their basic structural component is a conveyor belt. During storage and deployment, conveyor belts undergo an inevitable process of ageing which leads to deterioration of their properties. A challenge associated with the use of conveyor belts is to ensure the required electrical conductivity. This challenge has prompted the research into conveyor belts that was aimed at identifying their electrical conductivity, considering primarily the effects of ageing. Identification of electrical conductivity of newly manufactured conveyor belts is important for manufacturers in order to comply with relevant standards, and for conveyor belt users in order to eliminate potential hazards.**

Keywords **– Conveyor belt, electrical conductivity, ageing, quality, properties.**

1. Introduction

A conveyor belt is a complex composite consisting of rubber cover layers and a carcass formed of fabric or steel materials. Conveyor belts must endure harsh operating conditions, such as dynamic impact forces at chutes, which may be eliminated by using enclosed rubber conveyor belts and thus reducing the quantity of chutes to a minimum [1], [2], [3]. Other negative factors include mechanical and ozone ageing and wearing of belts [4], [5], [6]. When transporting hot materials or coal in gassy underground mines with a risk of methane or coal dust explosion, safety of belt conveyors is one of the key factors. Risk of fire must therefore be constantly evaluated in order to improve safety of belt conveyors [7]. For example, authors Pačaiová et al. [8] developed a methodology based on 19 safety requirements. It is used to assess efficiency of the implemented safety measures for each machine and for the entire facility.

Conveyor belt manufacturing is preceded by the assessment of quality of rubber mixtures in terms of their physical and mechanical properties (strength, elongation, hardness etc.). If the mixtures meet all of the requirements regarding their parameters, they may be used for the production of rubber-textile or steel-cord conveyor belts. Rubber mixtures represent a key component in the production of conveyor belt covers. They are formed of elastomers, which are insulators (dielectrics) that acquire conductivity after the addition of a fine-crushed or colloidal filler with high inner conductivity, such as carbon blacks. Over the years, a considerable amount of information has been published on measuring conductivity and on the factors that affect conductivity of such compounds or composites. With regard to the physical processes associated with electrical conductivity, several authors have proposed various mechanisms [9], [10], [11], [12], [13], [14].

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In paper [9], Medelia discussed electrical conductivity as an important property of various blends of rubber and plastics, including antistatic applications, wire and cable packaging. Apparently, multiple physical processes are involved, while a dominant process depends on the composition of a particular composite and on the measurement conditions. The author investigated into mechanisms of conduction in coal black composites and non-conductive polymers. Conductive (antistatic) materials and their use were understood differently by different experts in terms of designs and structures of conveyor belts. The main purpose of using conductive rubbers and plastics is to prevent generation of electrostatic discharges. When a belt surface is in perfect contact with a surface of a drive pulley or an idler, their charges are transferred from one surface to another. The most common conductive component in rubber or PVC is coal black (black particles of coal produced by combustion of combustible materials); nevertheless metal powders or fibres, glass spheres or fibres with metal coating and coal fibres are used too and they may provide high conductivity [10].

Authors of paper [11] studied thermal conductivity of polytetrafluoroethylene (PTFE) using the Lees' disc apparatus intended for measuring thermal conductivity. They conducted research on the effects of incorporating fillers into a PTFE/fibreglass fabric that is used for conveyor belts in food processing. They monitored the effects of crystallinity on thermal conductivity and compared various methods for crystallinity determination and PTFE thermal conductivity values for various degrees of crystallinity. Experimental measurements confirmed that thermal conductivity of PTFE increased with increasing crystallinity at 232 °C. Authors Zhang et al. [12] analysed the macro-electrical properties and microscopic structures in SEM samples of nanomaterials used in modified transfer belts, and investigated into the effects of nanomaterials and polymers on changes in rubber and temperature in the refining process. They examined the meshing changes and the key changes in the filler volume and the filling time of a plastic chain on conductivity of conveyor belts used in coal transportation. The authors discussed a microscopic mechanism of changes in macro-conductivity of conveyor belts.

Kim et al. [13] studied generating and maintaining high-level triboelectric charges that may damage electronic display components due to electrostatic discharges. The tested parameters included the effects of acceleration/deceleration and the maximum speed, relative humidity, moist on glass and idlers, and idler conductivity. Triboelectric charging increased when the relative humidity increased from 30% to 50% at a constant temperature. Authors Wang et al. [14] examined highly conductive belts, which are particularly antistatic thanks to their conductive upper and lower surfaces. The measurements were made in compliance with ISO 21178, and the electrical surface resistance of the upper and lower sides was ROA $<3\text{x}10^8$ Ω. In most types of belts, surface resistance (ROA) of the upper and lower sides was even lower than $1\text{x}10^7$ Ω, i.e. significantly below the limit prescribed by DIN-EN ISO 284. Also, many types of belts exhibited a volume resistivity of $<1\text{x}10^9$ Ω, which was verified as prescribed by ISO 21178. HC belts are particularly suitable for the transport of electronic parts and for the transport during which the belts become charged, which has a negative effect on product quality, for example in the textile and chemical industries. If safety belts are to be electrostatically safe, only HC belts should be used for their production.

The key changes in conveyor belts that are caused by ageing initially appear on the surface that is in direct contact with a transported material or the surrounding air. Chemical changes caused by ageing result in changes in the physical properties of belt components, such as mesh density, glass transition temperature etc. Authors Nedbal et al. [15] investigated into ageing of conveyor belts caused by exposure to aggressive external operating conditions. Authors Feyzullahoglu and Arslan [16] studied mechanical ageing of rubber materials of conveyor belts that was caused by various working conditions, such as natural weathering (exposure to temperature, oxygen and ozone), as well as the effects of oils and acids, depending on mechanical properties of rubber mixtures. Their research has confirmed that, for example, styrene-butadiene rubber (SBR) is particularly suitable for materials used in conveyor belts. Fu et al. [17] developed a novel strategy for preventing blooming of antioxidants and improving resistance to ageing of SBR based on the use of carbon nanotubes (CNTs) loaded with antioxidant N-(1,3-dimethyl)butyl-N′-phenyl-p-phenylenediamine (4020) as a filler. Resistance to ageing of SBR/CNT composites was compared by testing their mechanical properties before and after exposure to thermal-oxidative and ozone ageing. Rubber composites exhibited the thermal conductivity of 0.303 W/m.K and electrical conductivity of $4.74\text{x}10^7$ Ω.cm; such values facilitate long service life of tyres and antistatic conveyor belts.

The experimental measurements were primarily aimed at studying rubber cover layers made of rubber mixtures. The utility value and the service life of conveyor belts are primarily determined by quality and special properties of cover layers. The quality criteria for different cover layers are specified in relevant standards.

2. Theory and Calculation

Electrical conductivity is a physical parameter that expresses a conductor's ability to conduct the electric current. The higher conductivity, the higher electric current passes through a conductor at the identical voltage. A good conductor has a high conductivity value, whereas a poor conductor has a low conductivity value [18].

The basic unit of electrical conductivity is a siemens (S). Siemens is the SI-derived unit of electrical conductivity. 1 S represents conductivity of an electric conductor with the electrical resistance of 1 ohm.

Electrical conductivity is calculated as follows:

Option 1 is to apply the Ohm's Law:

$$G = \frac{I}{U} = \frac{1}{R} \tag{1}$$

wherein:
G is the el. conductivity [S];
I is the el. current [A];
U is the el. voltage [V];
and R is the el. resistance [Ω].

Numerically, electrical conductivity equals a reciprocal of electrical resistance.

Option 2 is to use material properties of the conductor [19]:

$$G = \gamma * \frac{S}{l} \tag{2}$$

wherein:
G is the el. conductivity of the conductor [S];
γ is the nominal conductivity of the conductor [Sm.mm^{-2}];
S is the cross-sectional area of the conductor [mm^2];
and l is the length of the conductor [m].

3. Material and Methods

3.1. Experimental Material – Conveyor Belt

The conveyor belt (Figure 1.) is a composite consisting of rubber cover layers and a carcass formed of a fabric material or steel cords.

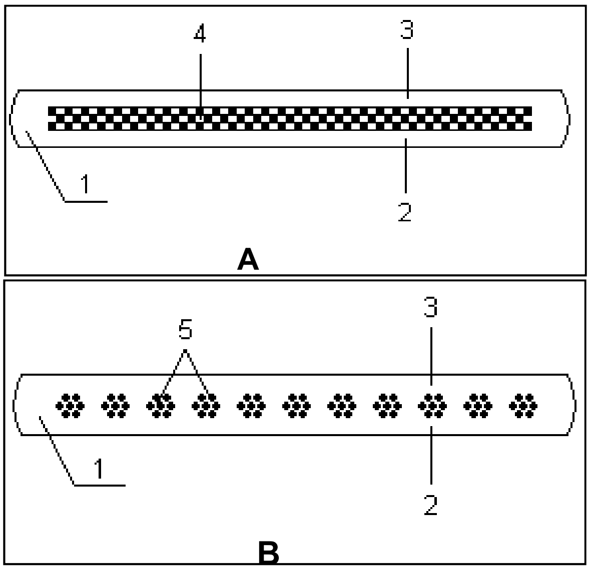


Figure 1. Conveyor belt cross-sections; A – rubber-textile; B – steel-cord; 1 – side protective edge; 2 – bottom cover layer; 3 – top cover layer; 4 – textile carcass; 5 – steel cord

The experimental measurements were primarily made for cover layers made of rubber mixtures. The utility value, i.e. the service life of a conveyor belt is primarily determined by the quality and special properties of its cover layers. Conveyor belts are rubber composites produced in compliance with the European, global and national standards and specifications [20].

The research was carried out while using the specimens of three different types of rubber-textile conveyor belts, in particular:

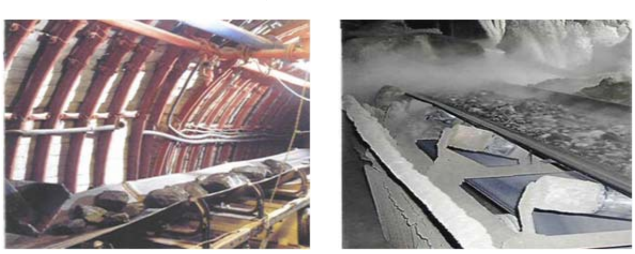
1. Transbelt (type P 2000/4, 8+4, A), a conveyor belt designed for general purposes and transport of abrasive, extremely abrasive, granular and loose materials. Its structure consists of a support carcass with rubber-textile plies and with polyamide and polyester plies. The carcass is protected by rubber covers that are designed to wear out. Typical Transbelt applications include transport of aggregates, limestone works, cement works, heat power plants, mining industry (e.g. during surface mining of coal for its transportation; Figure 2.a), recovery and processing of raw materials, dumps, docks, processing industry and agricultural industry.

2. *Thermbelt* (type EP 1000/5, 6+3, H), a conveyor belt with higher resistance to flame and with antistatic properties; it is intended for transport of materials in mines. This special type of conveyor belt is designed to handle hot lump and bulk materials. It is used for hot materials with temperatures above 60 °C (e.g. transportation of hot materials in iron work; Figure 2.c). Its structure consists of a carcass consisting of polyamide or polyester plies. The carcass is protected by rubber covers designed to withstand thermal stress generated by hot materials. Typical Thermbelt applications include heating plants, iron and steel works, metallurgical works, cement works, chemical industry and glass works.

3. *Firebelt* (type EP 315/2, 4+2, K), a conveyor belt with higher resistance to flame and with antistatic properties, intended for transport of materials in underground mines (e.g. in deep coal mining for its transportation; Figure 2.b) It is specifically designed for the transport of loose and lump materials in environments with a hazard of fire occurrence and spreading. Its structure consists of a support carcass with rubber-textile plies and with polyamide and polyester plies, or a support carcass consisting of steel cords arranged in a plane. The carcass of the belt is protected by the top and bottom covers and by the protecting edges on sides. Typical Firebelt applications include coal stockpiles, heating power plans, heating plants, coal preparation facilities and mining industry.

Preparation of test specimens is prescribed by STN EN ISO 284 [21] standard. A test specimen must be of a square shape and must be cut out with a full thickness of a belt. Its length and width must be at least 300x300 mm. Where possible, both sides of the test specimen must be cleaned with fuller's earth (i.e. hydrated magnesium aluminium silicate) using a clean cloth. After removal of all dust particles, the surface of the specimen must be wiped with a cloth soaked in distilled water and then immediately dried using a clean cloth.

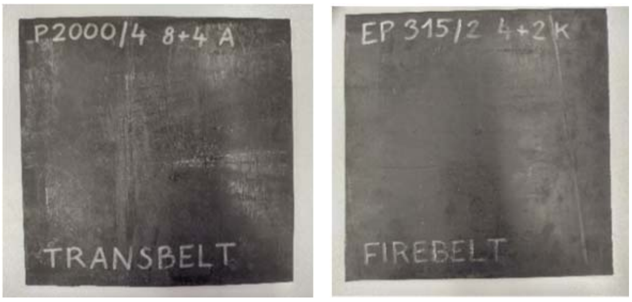
a) Transbelt



b) Firebelt *c) Thermbelt*

Figure 2. Conveyor belts in use

The belt specimens were produced out of three types of conveyor belts (Figure 3.).



a) Transbelt *b) Fireblet*

c) Thermbelt

Figure 3. Specimens of tested conveyor belts

The ISO 18573 [22] standard specifies the environment for conditioning and testing. Prior to the testing, specimens must be conditioned for at least 2 hours in a standard laboratory environment where the testing is to be carried out. A preferred temperature is 23 °C ± 2 °C and a relative humidity is 50% ± 5%.

Procedure:

1. The testing environment is checked.
2. Contact gel is applied on one of the surfaces on the test specimen, on two particular areas shown in Figure 4. Great emphasis is put on exact surface dimensions, whereas the symmetry of the surface centre is not important. If the test specimen is plain, gel may be applied to the bottom surface of the cleaned electrodes. If there is a texture on the surfaces, gel should be applied on the two areas on the specimen shown in Figure 4. The test must be carried out immediately after the gel is applied.
3. The test specimen is placed onto a plate made of an insulating material so that the tested surface faces up.
4. The bases of the brass electrodes are cleaned and placed onto the specimen, onto the surfaces coated with liquid contact agent.
5. Avoid breathing onto the surface of the test specimen since the condensed moist may affect the results.
6. The external electrode should be connected to a ground clamp or to a clamp with a lower voltage of a measuring device.

7. The internal electrode should be connected to a clamp with a higher voltage of a measuring device.
8. Resistance is measured after the voltage is in effect for at least 1 minute.
9. Electrical resistance of the tested belt is measured and recorded in ohms.

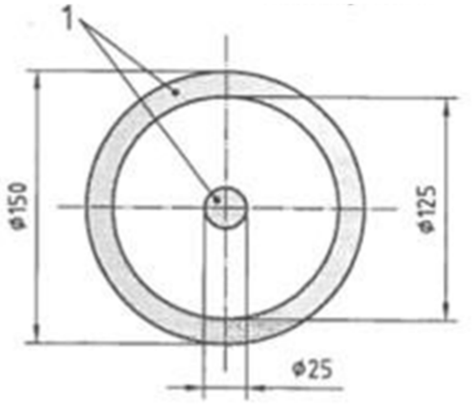


Figure 4. Coatings on the test specimen;
1 – contact agent

3.2. Electrical Conductivity – Specification and Test Method

Identification of a maximum electrical resistance of a conveyor belt is subject to STN EN ISO 284 [21] international standard. The test method is used to verify whether a belt is conductive enough to avoid accumulation of an electrostatic charge that may be generated while the belt is deployed in a conveyor. This international standard is not appropriate for testing light-duty conveyor belts, as described in EN 873 [23], for which the electrostatic properties are measured as specified in EN 1637 [24]. Electrical resistance of a conveyor belt, measured as described above, must not exceed $3x10^8$ Ω (300 MΩ). Lower values may be specified for special applications (STN EN ISO 21183-1 [25]). This section of STN EN ISO 21183 describes the key characteristics and applications of light-duty conveyor belts.

Test specimens were properly prepared out of the tested belt; subsequently, an electric current of a certain voltage was left to travel through the specimens using electrodes (Figure 5.). The following materials and devices were needed to perform the testing**:**

- A plate made of an insulation material, a bit larger than the test specimen;
- Two cylindrical coaxial brass electrodes, with one ring and the annular ring used as the bases; their dimensions and weights are shown in Figure 5. The bases of the electrodes must be flat and polished, and each electrode must be connected to a flexible insulated conductor.
- An ohmmeter (resistance measuring device) with a measurement range of up to 10^{10} **Ω** and accuracy of +5%;
- A DC source with voltage of up to 1,000 V that does not exceed 10 mA in the test specimen and does not cause spread of energy exceeding 1 W; a current source may be an accumulator or a rectified stabilised DC source;
- A contact agent for ensuring good contact between the electrodes and the test specimen, with a maximum electrical surface resistance of 10^4 **Ω**; the gel with an optimal composition is specified in Table 1.

Table 1. Optimal composition of a contact agent

Component	**Composition** Portions out of total weight
Anhydrous polyethylene glycol (molecular weight: 600)	800
Water	200
Potassium chloride	10
Soft soap (of pharmaceutical quality)	1

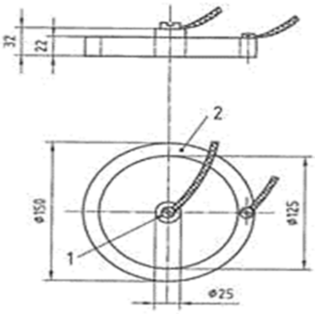


Figure 5. Electrodes;
1 – Electrode with a minimum weight of 115 g;
2 – Electrode with a minimum weight of 900 g

Electrical conductivity was tested on the Tera-Ohm Meter TO-3 (Figure 6.). Technical data of the measurement of high resistance (RxHigh) are as follows:

- Selected setting of a fixed test voltage of 10/100/500 V and a variable range from 1 V to 500 V;
- A test voltage tolerance of ± 0.2%;
- A maximum test current in case of short circuit < 3 mA;
- Continuous short circuit allowed;
- Measured values displayed in a scientific form (e.g. 17.45 E3 Ω means $0.17x10^5$ **Ω**);
- Failures/faults displayed on a LED screen for the test voltage; this error state is also sent to a computer.

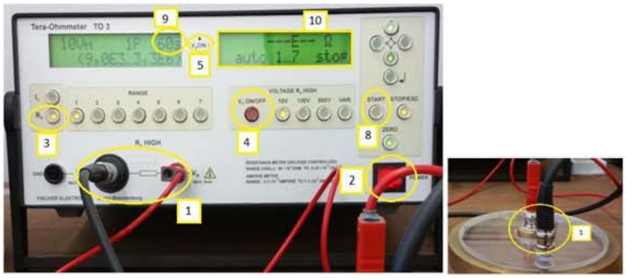


Figure 6. Fischer Tera-Ohm Meter TO-3

3.3. Accelerated Ageing Of Rubber – Specification And Test Method

Accelerated ageing is a test method for estimating disintegration of rubber by exposing it to accelerated ageing conditions (i.e. either by heating it in the air at the atmospheric pressure or in the oxygen environment at an elevated pressure). Different physical properties are measured at a standard laboratory temperature, and relative and absolute differences are applied to identify a relative service life of rubber. Methods specified in DIN 53 508 [26] are not suitable for the identification of the effects of light or ozone on rubber disintegration. For the purpose of the efficient assessment of resistance to ageing, it is necessary to take into consideration the intended applications of rubber by a user and to select the test methods and conditions that approximate those in the user's environment. Only the properties that are relevant to the intended use of the belts are examined.

Specimen ageing requirements:

- Test specimens must be conditioned and stored in standard atmosphere;
- Test specimens must not be tested earlier than 16 hours and not later than 4 weeks after vulcanisation (rubber refining with sulphur);
- Drying ovens must be pre-heated to the test temperature before the test specimens are inserted; test specimens must be protected against light and exposed to the air or oxygen on all sides;
- Test specimens must be placed at a minimum distance of 10 mm while a minimum distance from the oven walls is 10 mm (for cell ovens and pressure chambers) or 50 mm (for hot-air drying ovens).

Accelerated ageing tests were carried out using the Heratherm OMH series oven (Figure 7.), where the hot air is diffused by a fan (OMH stands for Oven with Mechanical Convection).

Figure 7. Conveyor belt specimens placed inside the Heratherm oven

The specimens of the Transbelt conveyor belt, type P2000/4, 8+4, A, Thermbelt conveyor belt, type EP1000/5, 6+3, H, and Firebelt conveyor belt, type EP 315/2, 4+2, K, were exposed to accelerated ageing with mechanical air convection at 100 C for 3 days. DIN 53508 specifies a permissible deviation of ± 1℃ for Heratherm OMH oven in thermal ageing. The oven settings were as follows: a closed controller; a fan with a set value of 60%, which corresponded to the air flow rate of up to 1m.s^{-1}. The oven instruction manual does not specify the air flow rates for the individual adjustable values.

Temperatures were recorded using Logger SO111. The records were saved in an electronic memory while the data may be transmitted at any time to a PC via a USB flash drive, Ethernet or GSM modem using a respective adapter.

The complete procedure of testing electrical conductivity and ageing of conveyor belts, i.e. the test methodology, is shown in Figure 8.

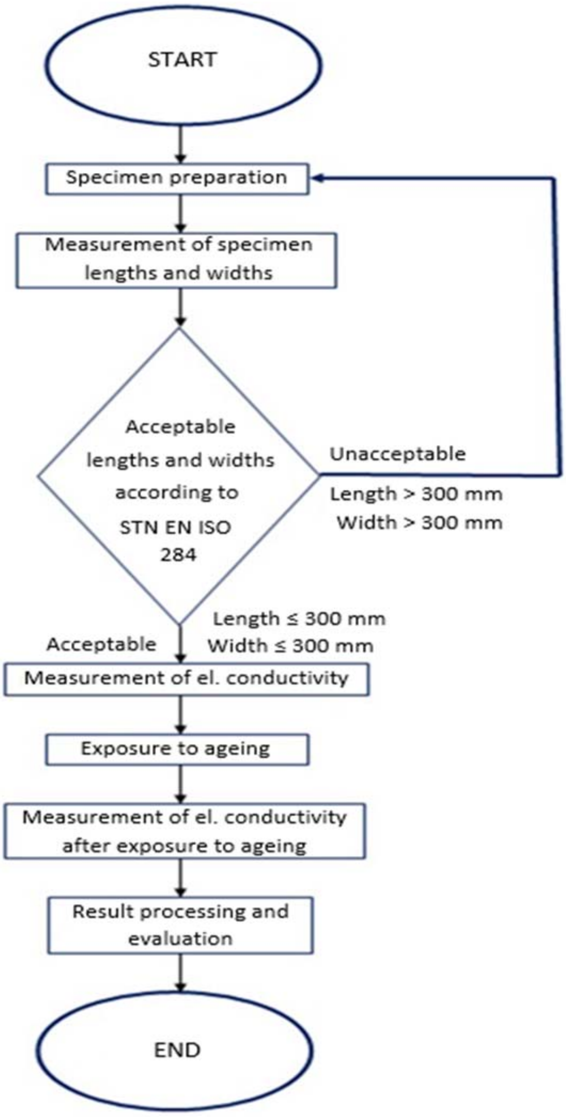


Figure 8. Methodology for measuring electrical conductivity and ageing of conveyor belts

4. Results and Discussion

The electrical conductivity testing was carried out using 3 types of conveyor belts (Transbelt, Firebelt and Thermbelt), tested before and after exposure to ageing (3 days). They were tested for conductivity (whether the conveyor belts exhibit sufficient conductivity).

The size of the tested specimens was 300x300 mm. The specimens were measured at 10V and the range was set automatically. The top cover layers of the conveyor belts were measured. The upper limit for electrical resistance (R) of a conveyor belt was 3×10^8 Ω (300 MΩ). The results are listed in Table 2. Resulting values of electrical resistances of the three tested conveyor belts, Trasbelt, Firebelt and Thermbelt, before and after exposure to ageing are shown in Figure 9. All three conveyor belts exhibited sufficient conductivity and they are all suitable for real-life applications as their resistances did not exceed 3×10^8 Ω (300 MΩ). Thermbelt and Firebelt conveyor belts were both sufficiently conductive and did not exhibit any sudden change in resistance after ageing; this means that they are suitable for real-life applications. However, although the Transbelt conveyor exhibited sufficient conductivity and did not exceed the resistance limit of 3×10^8 Ω (300 MΩ), after exposure to ageing (3 days) the measuring device did not detect any electrical resistance; as a result, it was not possible to assess whether its resistance was higher or lower than that before exposure to ageing.

Table 2. Values of resistances (R) of conveyor belts before and after ageing

Tested conveyor belts		
Conveyor belt type	**R before ageing [Ω]**	**R after ageing (3 days) [Ω]**
Transbelt	49.94×10^3	Not measurable
Firebelt	9.42×10^3	9.89×10^3
Thermbelt	13.02×10^3	13.31×10^3

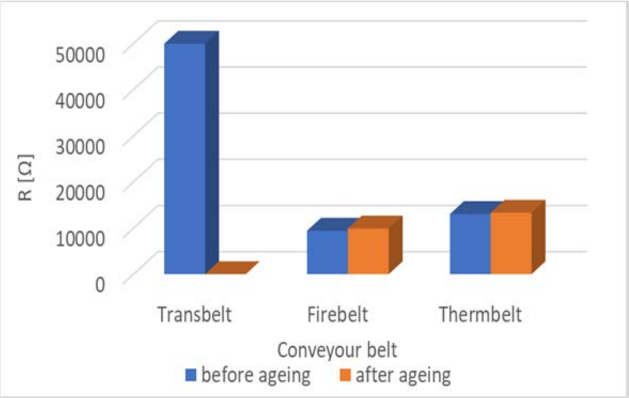


Figure 9. Plots of values of electrical resistances before and after ageing of conveyor belts

5. Conclusion

The purpose of this experimental study was to examine the quality of special properties of conveyor belts (electrical conductivity and ageing) in terms of different compositions of the used composites, in particular Transbelt, Firebelt and Thermbelt. This study, i.e. the testing of conveyor belt quality, has shown that all three types of conveyor belts meet the requirements specified by STN EN ISO 284 and confirmed the fact that a dominant process in conduction of electrical energy depends on the composition of a particular composite. Two of the tested composites, i.e. Thermbelt and Firebelt, exhibited higher quality in terms of electrical conductivity, which was measurable even after exposure to ageing. As for the Transbelt conveyor belt, its conductivity after ageing was not measurable within the determined range of values.

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