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An analysis of the possibility to develop trolleybus current brushes from recycled materials

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Abstract: The paper presents an analysis of the possibility of producing traction brushes from waste materials. Brushes are used to ensure good electrical contact between the rail and the pantograph. Slides are produced in the process of hot pressing, with parameters of heating up to max 175 °C, at the minimal pressure value of 200 MPa. The developed brushes with a high (55-60%) content of recycled materials have comparable characteristics to commercial brushes, and some of the prototypes are even more durable and break-resistant.

Keywords: trolleybus brushes; recycling; mechanical and electrical properties.

1. Introduction

Electro-mobility of public transport in cities has become an important issue in recent years, since passenger and freight transport consumes more than a quarter of global primary energy and is responsible for significant greenhouse emissions [1,2]. Trolleybuses are commonly perceived as a valuable alternative to conventional buses in sustainable urban transportation systems [3-6]. However the very presence of sliding current-carrying contact zone causes non-trivial problems. The traction brushes made of a mixture of graphite and copper filings have to be replaced on a weekly basis under standard operating conditions, because of their wear [7].

The issue how to assure a proper electric contact has been the subject of numerous research works and monographs, to mention [8-11]. It should be stressed that the problem is extremely complex, taking into account the roughness of the contacting surfaces, random occurrence of contact spots, elastic and plastic deformations, the presence of dirt, grease, soot burnouts as well as possible vibrations of the pantograph-catenary system. The interdisciplinary nature of the problem attracts researchers on materials science and tribology, physicists, mechanical and electrical engineers.

Senouci and co-workers [7] focused on anisotropic electrical and mechanical properties of graphite. The authors have noticed that the friction and wear behavior of copper-graphite are influenced by the magnitude of electrical current. The authors have also examined the effect of contact polarity on the surfaces of contact, on the transferred layers, on the contact electrical potential and on the contact wear.

One of the most commonly used theories concerning the electrical contact resistance between two metal surfaces was developed more than fifty years ago by R. Holm (the year of publication of his monograph [8] is considered in this context (fourth edition, most often cited), however Greenwood refers in his paper [9] to the results obtained by Holm presented in 1929 in a newsletter issued by a commercial company). Briefly speaking, Holm assumed the true points of contact (referred to as a -points) between two jagged surfaces might be approximated as ellipses. Next he computed the contact resistance from the relationship $R_S = \frac{\rho}{4a_c} f(\gamma)$ where $\gamma = \sqrt{a/b}$ is a geometric quantity (the ratio of two semi-axes of the ellipse), ρ is material specific resistivity whereas a_c is the

radius of equivalent circular spot with area equal to that of the elliptical a -spot. Next the theory was extended to cover the case of similar a -spots, cf. Fig. 1, leading to the relationship

$$R = \rho \left(\frac{1}{2na} + \frac{1}{2\alpha} \right)$$

where a is the mean a -spot radius (obtained from the averaging $\sum_i a_i/n$ (a_i is the radius of i -th a -spot, n – the total number of a -spots), whereas α is the radius of the cluster of a -spots, referred to as the Holm radius.

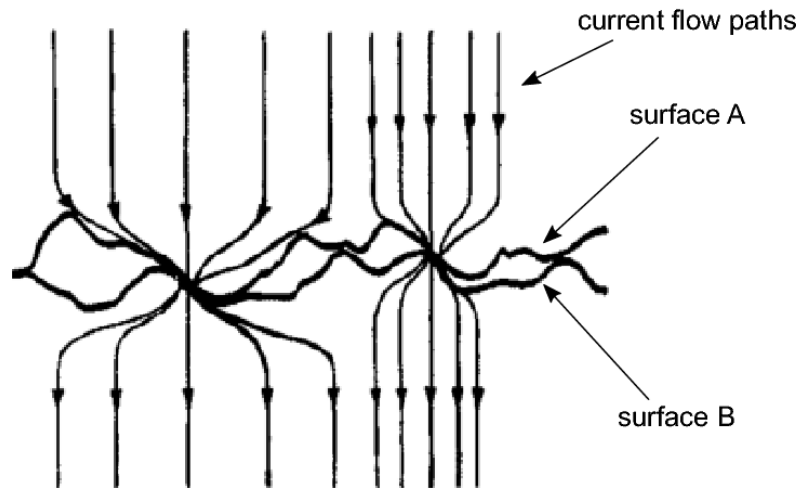


Fig. 1. A sketch representing contact points and current flow between two surface

The Holm theory has been in use for several decades and a number of its refinements has been suggested to take into account different factors. It should be remarked that there is an annual international conference on electrical contacts, called the Holm conference [13]. Generally, the theory is valid for contacts with size much larger than the mean free path of the electrons. Mikrajuddin *et al.* [14] suggested an expression for the contact resistance which in the limiting cases reduces itself to the Holm resistance and the Sharvin resistance (which is relevant for nano-electronic devices). Kogut and Komvopoulos [15] derived from the first principles a general electrical contact resistance theory for conductive rough surfaces. The analysis was based on fractal geometry for the surface topography description, elastic-plastic deformation of contacting asperities, and size-dependent constriction resistance of microcontacts. Subsequently [16] the authors extended the validity of their theory by taking into account the presence of a thin insulating film between the rough surfaces, which was treated as an energy barrier that impeded current flow due to the electric-tunnel effect. The authors suggested that constriction resistance (computed from the Holm theory) played a less significant role in the electrical contact resistance theory than the tunneling effects occurring in the thin film layer. Next Kogut developed a refinement of his theory to cover the case, where there is a significant contamination of electrical contacts [17].

Regarding rather experiment-oriented than theory-oriented papers, the following contributions should be accounted: Midya *et al.* [18,19] focused on electromagnetic compatibility issues, namely pantograph arcing and the related phenomena (distortion of supply voltage waveforms, conducted and radiated emissions etc.). Samodurova *et al.* [20] described a novel simplified technology of production graphite-plastic brushes in a single step. The main forming operation is carried out with the unit pressure of 30-40 MPa, at temperature from the range 150-170°C. The semi-finished product is held under press for 3-5 minutes. Wu *et al.* [21, 22] examined the evolution of the electrical contact between pantograph and catenary with respect to electrical conductivity, temperature rise, as well as microstructure variation. The evolution mechanisms were discussed on the basis of Scanning Electron Microscopy (SEM) based microstructure analysis of five typical morphologies (craters, dull-red areas, bright areas, dark stream lines and pits). The authors

examined the effect of electric current on contact resistance and found that for smaller current values the decrease of contact resistance is more abrupt. Moreover, by means of infrared thermography they have found that temperature rise under current-carrying conditions is significantly higher than for pure friction, current-free regime. This led them to the conclusion that the electric effect takes a dominant role in the temperature rise of carbon strips and heat accumulation regions are formed due to pantograph arcing. Moreover the authors noticed significant wear morphology differences under pure friction and current-carrying conditions. Khusnutdinov *et al.* [23] described a practical problem, similar to the one being addressed in this contribution: how to increase the service time of electrical brushes? The concept, introduced in Kazan public transport system, was to introduce a novel design of the brush holder, which allows one to reduce the cost of a new brush by 28.8% and to increase the service time of the brushes by 30%. Two recent open source papers [24, 25] focused on yet another problem persistent for the pantograph-based supply units, namely the stability of the contact and possible vibrations of the pantograph head.

From the presented literature review it can be seen that the issue of energy transfer in the pantograph-catenary system is certainly an important subject of study for scientists and engineers representing different disciplines. The present paper is focused on the possibility to develop trolleybus brushes with competitive mechanical and electrical properties compared to commercial solutions using recycled materials. In this context, the present paper is similar to the publications [20] and [23].

2. Materials and Methods

Traction brushes should fulfill their basic function, i.e. they should be used in current collectors from the traction lines at various DC loads and be able to withstand higher levels of vibrations and thermal shocks, not to damage the traction network due to the friction (brushes should wear out uniformly and contain an oiling substrate, lubricating the traction wires), be used as long as possible, what reduces the operating costs of public transport vehicles. This means an extension of the average time of their use (1 week) and getting rid of the problem of replacement caused by their cracks during operation.

The concept was to avail of the recycled materials, wherever possible. For this purpose, materials obtained from local metal processing companies were obtained, selected, cleaned and crushed. The proposed solution is based on the hypothesis that very fine dust (<50 microns) from exhausted carbon electrodes can be used for the production of traction slides (Fig. 2), with the addition of pure graphite powder, reinforcement in the form of copper fibers derived from shredded braids of power cables.

Proper lubricating properties are ensured by particles of the cooling lubricant remaining from the material processing process, trapped in the structure of the composite and the natural lubricating properties of graphite. Phenolic-acrylic resin was used as the jointing material – cf. Fig. 2. Figure 3 presents a photograph of ready-made product.



Fig. 2. Components for making up trolleybus brushes from recycled materials, a) carbon powder made from used electrodes, b) shredded copper braid, c) phenolic-acrylic resin



Fig. 3. An exemplary ready-made brush

3. Measurements and results

The research was carried out for various component mixtures and for commercially available brushes. Electrical, mechanical and load properties were tested. It should be remarked that the some electrical properties (e.g. current ampacity) were examined using a laboratory stand at direct current value equal to 150 A, what might be considered as a value comparable to those obtained in real-life conditions.

Figure 4 presents a photograph of the laboratory stand for testing current ampacity, whereas in Figure 5 the connection scheme of the setup is presented.



Fig. 4. A photograph of the laboratory stand for testing current ampacity

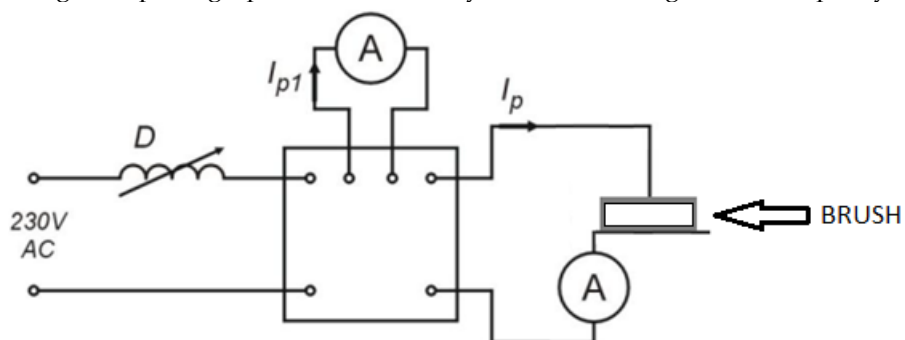


Fig. 5. The connection scheme of the setup

The measurements of electrical resistance were carried out using the bridge method with the Sonel MMR-650 device. A sketch of the connection scheme to the device is presented in Fig. 6.

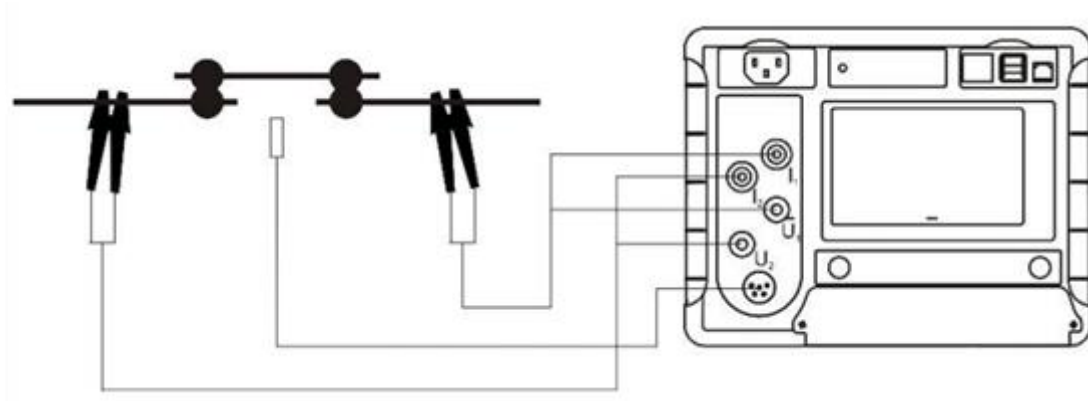


Fig. 6. A sketch presenting the connection of brushes to the Sonel MMR-650 device

Exemplary measurement results concerning the resistance of the samples are given in Table 1. Description of the samples: 1 – graphite + 20% resin + 20% copper, 2 – original mixture, designated as RH84, 3 – graphite +15% resin + 20% copper, 4 – another original mixture, designated as MY7D, 5 – graphite + 20% resin + 20% copper + 30% graphite recyclate, 6 – graphite + 20% resin, 7 – graphite without resin.

Tab. 1. Resistance of the samples

sample	1	2	3	4	5	6	7
resistance (mΩ)	8.63	7.23	6.45	8.67	9.84	14.85	6.37

Hardness tests were carried out with the HB ball indentation method in accordance with PN-EN ISO 2039-1: 2004. During the tests the ball with diameter 5 ± 0.05 mm was used. The successive load values were 49 N, 132 N, 358 N and 961 N. The measurements were made at the distance at least 5 mm away from the sample edge, the distance between successive measurement point was 10 mm. The tests were carried out on samples with smooth, even, mutually parallel and perpendicular surfaces to the direction of the force, without bubbles, scratches, pits and other visible defects. The tests were carried out at variable temperatures of 80°C, 23°C, and -32°C. The results are shown as graphs in Figures 7-9. Designation of the samples: 1 – graphite + 20% resin +20% copper, 2 – original commercial component, tradename RH84, 3 – graphite + 15% resin +20% copper, 4 – another original commercial component, tradename MY7D, 5 – graphite + 20% resin + 20% copper + 30% graphite recyclate, 7 – pure graphite without resin.

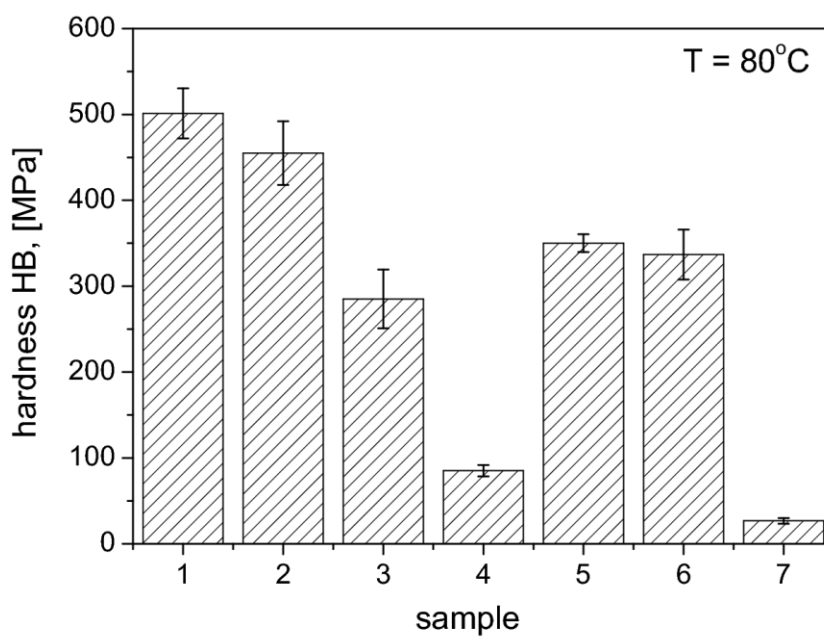


Fig. 7. Hardness HB at elevated temperature (80°C)

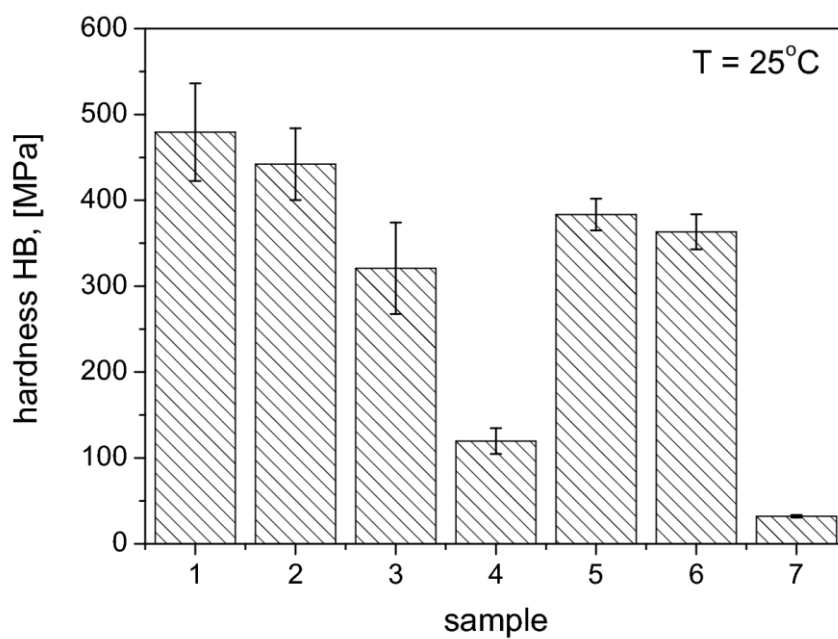


Fig. 8. Hardness HB at room temperature (25°C)

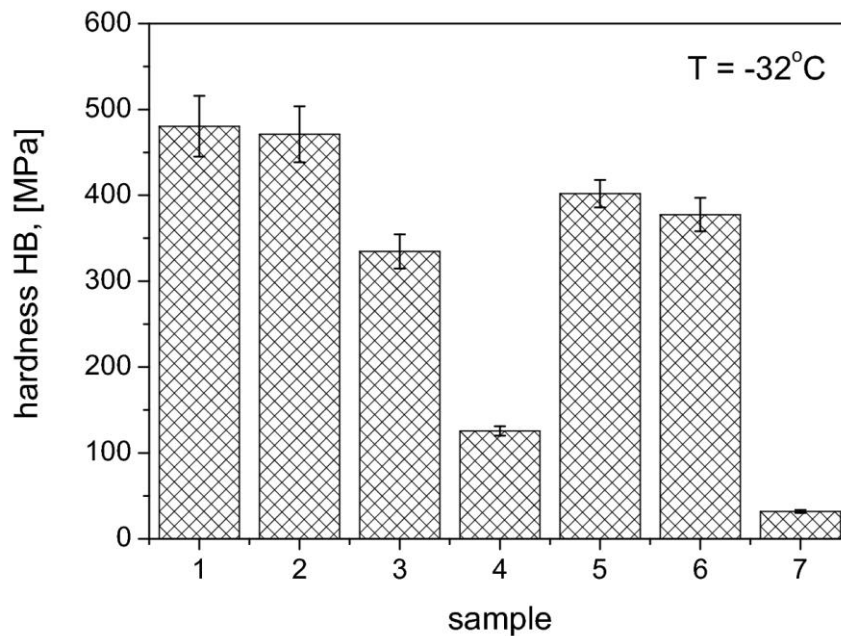


Fig. 9. Hardness HB at temperature below zero Centigrade (-32°C)

Commercial brushes made of commercial mixtures reveal considerable hardness (in particular the mixture RH84), but it varies to some extent with temperature variations. For the RH84 mixture an increase in hardness was recorded at lower temperatures, whereas for the M7D mixture the hardness values were noticed both for the room and for the negative temperatures. The lowest hardness values were recorded for the graphite samples with 20% resin content and for graphite samples. Graphite samples with the addition of graphite recycle, resin and copper, as well as graphite samples with the addition of resin and copper, possess higher hardness values than the original commercial mixtures.

Table 2 presents the results related to abrasion tests for some of the considered brushes. Notation: RH84 and WY7D denote commercially available compositions; S1 – a mixture of carbon recycle, “new” carbon and 15% copper and resin; S2 – a mixture of carbon recycle, “new” carbon and 15% resin; S3 – a mixture of “new” carbon and 15% copper and resin. $\Delta 10$ denotes the loss in brush weight, in grams, after sliding it for 10 meters distance along the traction wire, $\Delta 100$ – after sliding it for 100 meters distance, respectively. These values are also referred to the original brush weights and given in percentage units (denoted as $\Delta 10\%$ and $\Delta 100\%$, respectively). From a comparison of the weight loss results a conclusion may be drawn that the wear performance of sample S1 is superior to other presented ones.

Tab. 2. Loss in brush weight after sliding

	$\Delta 10$, g	$\Delta 10\%$	$\Delta 100$, g	$\Delta 100\%$
RH84	0.05	0.09	0.15	0.26
WY7D	0.044	0.05	0.114	0.14
S1	0.03	0.03	0.16	0.14
S2	0.07	0.07	0.28	0.29
S3	0.09	0.08	0.52	0.49

Conclusions

The research was necessary in order to select the optimal composition of the mixture, which will ensure the best possible electrical and mechanical values and the possibility of processing in the process of hot forming at temperatures up to 175°C, minimal compaction pressure 200 MPa. This task is to eliminate compounds that contain ingredients that can cause corrosion of the traction line or reduce the life of the brushes. As the result, mixtures were prepared from which prototypes of traction contact brushes can be made. The developed brushes contain 55 - 60% recycled materials. They are fraction-resistant and definitely more durable than their commercial counterparts. Moreover they are customized to varying ambient conditions (summer, winter temperature variations).

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