RESEARCH OF Sn AND Zn IMPREGNATED CARBON MATERIALS FOR RAILWAY SLIDING STRIP

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Abstract

Electric traction is a complex energy supply system for electric locomotives. One of the most important components of this system, to ensure continuous current flow, is a pantograph contact strip. It is a part of pantograph located on top of traction vehicles which allows them to move within the electric traction through constant sliding contact with contact wires. This paper presents method of fabrication and selected properties of metallic-carbon composite materials dedicated for sliding strips used in railway systems. Porous carbon materials prepared for metal infiltration were produced by mixing of carbon powders with a binder, extrusion of the resultant slurry through a suitably profiled die, thermal debinding and sintering. Developed carbon materials are characterised by open porosity in the range of 4-15% calculated by the difference in weight for the same volume of tested samples. Obtained carbon materials were next impregnated by molten zinc and tin with the use of gas-pressure infiltration process. The results showed that mechanical properties and electrical resistivity of obtained materials were enhanced as a result of metal impregnation. Additionally, microstructural characterization of the composites showed structure of the interpenetrating network of phases, the absence of unfilled pores and good cohesion at the carbon - metal interface.

Keywords: Railway, railway traction, carbon strips, current collector, metal impregnation

1. INTRODUCTION

Overhead line is a complex system consisting of two main components, the catenary and the traction return path. This system allows rail vehicles to travel by continuously supplying electricity through a series of wires and lines suspended on support structures and various types of catenary equipment. Electricity is supplied to the trains by direct contact of the catenary wires with contact strips located on the pantograph of the electric locomotive [1-3]. In Poland, copper contact strips had been used until 2011, which had a positive impact on the transmission of electricity. On the other hand, the strip material caused rapid abrasion of the catenary wire, which is expensive to replace. In addition, trains equipped with such contact strips could not travel on overhead line networks in other European Union countries that already used dedicated solutions to reduce the wear of catenary wires (different contact strip material based on graphite or graphite composites). Due to the lack of local solutions, foreign carbon contact strips have been adapted to the national requirements described in the Iet4 document issued by PKP (Polish Nationals Railways). Contact strips according to PKP regulations should be characterised by such parameters as: hardness not higher than 120 HRB, resistivity below 5 µΩ·m and metal content in carbon composite below 40 % [4]. Carbon and carbon-metallic contact strips, in addition to high tribological properties, which have a positive effect on the low wear of the contact wires, are highly resistant to electric arcs occurring in the absence of contact between the contact wire and pantograph strip. Carbon and carbon-metal composites have significantly lower electrical and thermal conductivity compared to copper contact strips. Currently, extensive research is being carried out around the world to produce carbon composites with the addition of metal particles to increase their working properties through low electrical resistance and high strength of contact strip material, which will be dedicated to high speed trains [5-7]. Analysing literature, we can also find research on the possibility of addition of various compounds, i.e. MoS_2, WS_2, Al_2O_3, to improve the strength properties of carbon composites [8-11] and heat treatment increasing the strength properties of carbon material [2]. The article presents research on the possibility of pressurised infiltration of carbon and carbon-metal composites using liquid metal. Zinc and tin were selected for the study because of the significantly lower melting point than copper and the favourable castability of liquid metal. The carbon materials produced were subjected to microstructural tests, tests of electrical properties, bending strength and hardness.

2. MATERIALS AND METHOD

Carbon and carbon-based composite with suitable porosity, intended for testing pressure infiltration with liquid metal was produced by blending the powdery carbon materials, extruding them using a screw extruder into finished carbon strips, and then subjecting them to final heat treatment. Pure carbon composite was produced on the basis of pitch coke with a fraction of 0.6-0 mm, petroleum coke with a fraction of 0.6-0 mm and F110 binder. In the case of carbon-metal composite, copper powder with a fraction of 60 µm was added. A PP-140 press equipped with a feeding and pressing screw was used to obtain the carbon strips of a particular shape designed for the overhead line systems. Heat treatment was carried out in the next step, taking into account three main stages, i.e. drying, polymerisation and firing at temperature up to 1100°C for 624 hours. Open pores formed in the carbon composite during heat treatment, permitting infiltration with liquid metals to enhance the electrical and strength properties of the composite. In addition, carbon and carbon-metal composites were obtained after the heat treatment without any external or internal defects (**Figures 1 - 2**). **Table 1** below shows the physical and mechanical properties of the obtained carbon and carbon-metal composites, intended for further research.

Table 1 Physical and mechanical properties of carbon samples

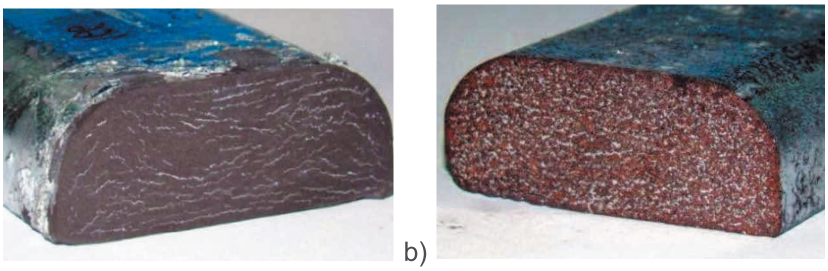
Properties	Unit	C sample	C/Cu sample
Apparent density	g/cm^3	1.70	2.08
Bending strength	MPa	33.5	18.3
Compression strength	MPa	65.3	60.2
Water absorption	%	2.4	7.8
Porosity	%	4.0	16.1
Hardness	Sh	100	89.2

a)

b)

Figure 1 Macrographs of sintered a) C and b) C/Cu samples

The materials developed have an open porosity structure that allows infiltration with liquid metals, i.e. mainly zinc and tin. For the saturation tests, a testing station designed at the Silesian University of Technology and manufactured by Czylok was used, intended for pressure infiltration of porous carbon materials with various metals and metal alloys. During research, samples of carbon and carbon-metal composites were attached to a movable piston located in the upper part of the device (PTA-8/PrGC2P Czylok). Runners for saturation metals were placed in the bottom part of the heating device, the device's container was hermetically sealed and an inert gas, i.e. nitrogen, was introduced. The furnace was heated up to 400 °C in the case of tin and up to 500 °C for zinc. The melted metal was kept at this temperature for 1 h, which allowed for its complete melting and homogenisation. Then, the piston of the device was lowered below the liquid metal level and pressure was increased to 1.5 MPa and 3 MPa. After a period of 15 minutes, protective gas was removed and the samples of carbon and carbon-metal composite were removed for full cooling. **Figures 3 - 4** show the macrostructure of model carbon and carbon-metal composite samples.



a) b)

Figure 2 Macrographs of samples impregnated using melted zinc a) C and b) C/Cu

Microstructural samples were subjected to grinding and cold polishing using abrasive SiC materials, followed by microstructural observations using the Zeiss Axio Observer optical microscope. The hardness of the carbon and carbon-metal composites was analysed using a FUTURE-Tech machine at a specified indenter workload of 100 g. Bending strength was determined using the ZWICK Z020 strength machine with three point bending tooling (**Figure 3**). Resistance of carbon and carbon-metal composites was measured using a four-point method on Burster Resistomat 2304 (**Figure 4**) in two directions, i.e. according to the current flow in the overhead line and in the cross section of the composite.

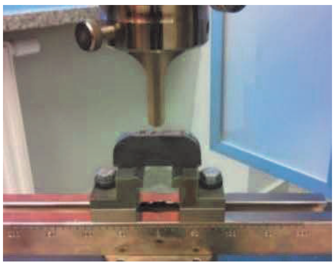


Figure 3 Bending strength test

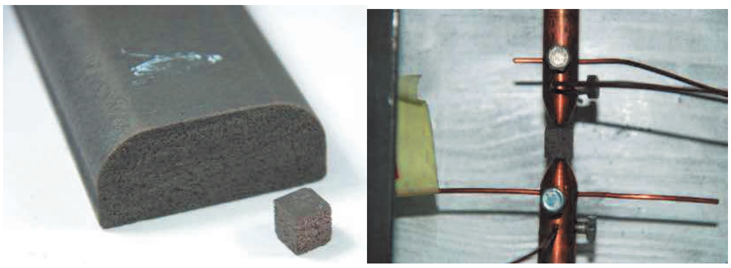


Figure 4 Sample electrical resistance

3. RESULTS AND DISCUSSION

The results of microstructural tests of carbon and carbon-metal composites saturated with zinc and tin are shown in **Figures 5 to 8**.

Microstructural tests show that saturation with liquid zinc and tin at a preset pressure of 1.5 MPa and 3 MPa enables infiltration of carbon and carbon-metal composites. By analysing the results of microstructural tests of the obtained materials, it can be stated that at the pressure of 1.5 MPa and the saturation with both zinc and tin, there is an incomplete filling of the continuous, strongly branched pores of the carbon and carbon-metal composites (marked with the red arrow on **Figures 5a, 6a, 7a, 8a**). In the case of using higher pressure, i.e. 3 MPa, there was a much larger filling of the open pores of the material, which is characterised by larger areas with a more uniform structure and the amount of infiltrated metal. In addition, in the case of carbon-metal composites containing copper powder, it can be observed that the infiltrated liquid metal in contact with the copper particles is likely to result in the formation of bronze alloy in the case of tin and brass alloy in the case of zinc, due to diffusion in high temperature and a period of 30 min (marked with a blue arrow on **Figures 7b, 8b**).

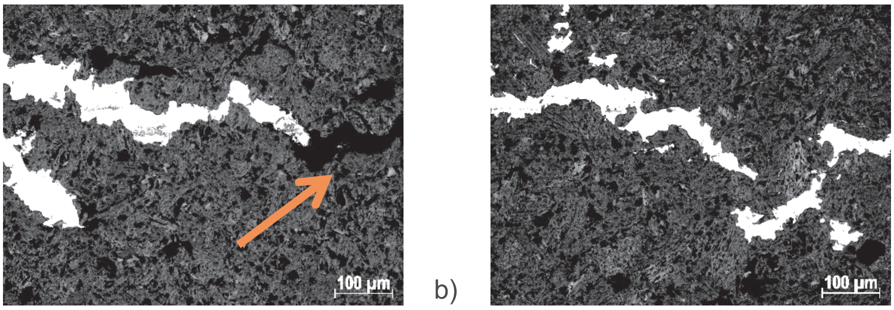
a)  b)

Figure 5 Microstructure of C sample impregnated by melted tin under pressure of a) 1.5 MPa; b) 3 MPa

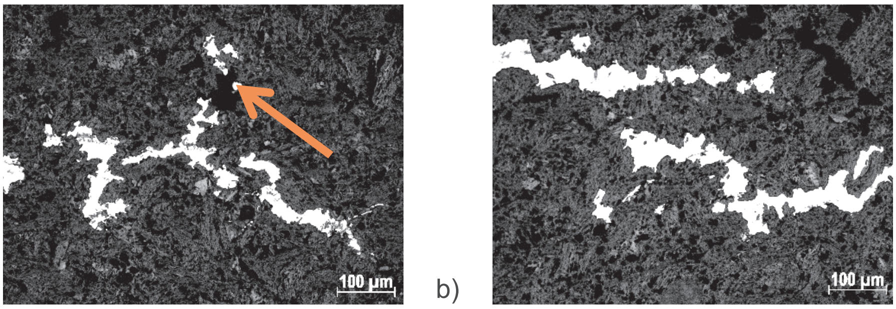
a)  b)

Figure 6 Microstructure of C sample impregnated by melted zinc under pressure of a) 1.5 MPa; b) 3 MPa

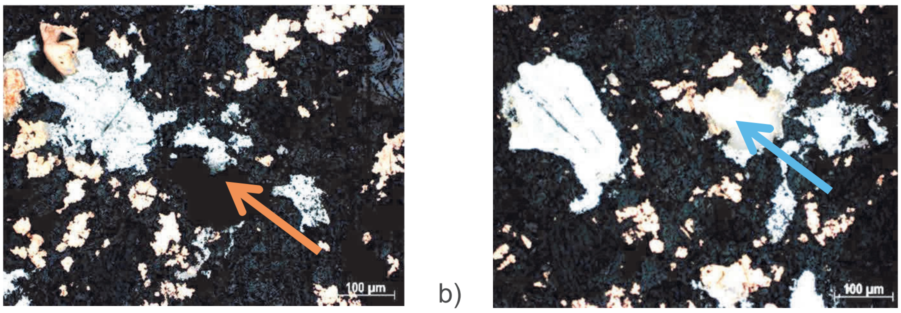
a)  b)

Figure 7 Microstructure of C/Cu sample impregnated by melted tin under pressure of a) 1.5 MPa; b) 3 MPa

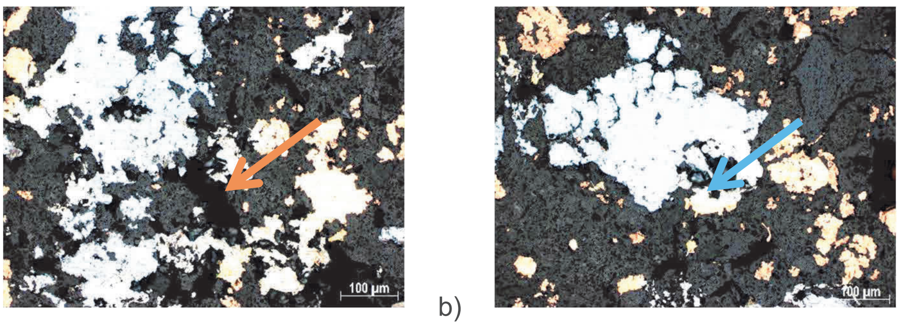
a)  b)

Figure 8 Microstructure of C/Cu sample impregnated by melted zinc under pressure of a) 1.5 MPa; b) 3 MPa

Studies of electrical properties of saturated composites shown, that in the case of both materials resistance was comparable in both measured directions. By analysing the results of the electrical tests of carbon composite, it can also be stated that these composites also exhibit comparable properties in both analysed current flow directions. Saturation with Zn and Sn results in a decrease in electrical resistance to approximately 0.27 Ω, which is about 30 % of its initial resistance compared to carbon composite. The carbon-metal composite exhibits the most favourable electrical properties after saturation with Zn and Sn - resistivity of 0.1 Ω (resistance drop by 57 %). **Table 2** presents the results of the tests.

Table 2 Summary of the electrical resistance test results of obtained composite

No.	**Carbon composite**	**Metal**	**Impregnation conditions**	**Electrical resistance in the current flow direction (longitudinal)** (Ω)				**Electrical resistance in the transverse direction** (Ω)			
				1	2	3	Average	1	2	3	Average
1	C	-	-	0.26	0.41	0.36	0.343	0.33	0.41	0.36	0.37
2	C	Zn	500 ˚C,1.5 MPa	0.27	0.34	0.26	0.293	0.32	0.25	0.29	0.29
3	C	Zn	500 ˚C, 3 MPa	0.28	0.25	0.30	0.278	0.24	0.28	0.27	0.26
4	C	Sn	400 ˚C, 1.5 MPa	0.22	0.36	0.32	0.297	0.28	0.30	0.28	0.28
5	C	Sn	400 ˚C, 3 MPa	0.28	0.26	0.27	0.267	0.23	0.29	0.27	0.27
6	C/Cu	-	-	0.20	0.25	0.24	0.230	0.26	0.26	0.29	0.27
7	C/Cu	Zn	500 ˚C, 1.5 MPa	0.17	0.16	0.17	0.167	0.14	0.11	0.18	0.14
8	C/Cu	Zn	500 ˚C, 3 MPa	0.13	0.13	0.10	0.118	0.13	0.13	0.13	0.13
9	C/Cu	Sn	400 ˚C, 1.5 MPa	0.11	0.10	0.09	0.100	0.11	0.17	0.15	0.14
10	C/Cu	Sn	400˚C, 3 MPa	0.10	0.10	0.11	0.103	0.13	0.13	0.16	0.14

Research on the mechanical properties of carbon and carbon-metal composites saturated with Zn and Sn showed that saturation with metal increased the bending strength. Carbon composites saturated at 3 MPa have a bending strength of 46 MPa in the case of zinc saturation and 50 MPa for tin saturation, which is more than a 30 % increase compared to pure carbon composite. In the case of saturation of carbon-metal composites with zinc, the properties of the composite increased from 18 MPa (unsaturated carbon-metal composite) to about 40 MPa, and in the case of tin to an average level of 45 MPa. Hardness tests of the material produced as part of the research showed that saturation with Zn and Sn resulted in a noticeable increase in hardness. In the case of zinc saturation at the pressure of both 1.5 and 3 MPa, carbon strips have a hardness of about 70 HRF, while carbon-metal composites of about 48 to 59 HRF. Saturating the carbon composite with tin at the pressure of 3 MPa produces an increase in hardness of up to 53 HRF, while in the case of carbon-metal composite, to 33 HRF.

Table 3 Results of bending strength test of studied samples

No.	**Carbon composite**	**Metal**	**Impregnation conditions**	**Bending strength** (MPa)	**Hardness HRF**
1	C	-	-	33.5	20
2	C	Zn	500 ˚C, 1.5 MPa	39.6	71.4
3	C	Zn	500 ˚C, 3 MPa	46.4	67.3
4	C	Sn	400 ˚C, 1.5 MPa	45.1	46.4
5	C	Sn	400 ˚C, 3 MPa	50.0	53.5
6	C/Cu	-	-	18.3	15.6
7	C/Cu	Zn	500 ˚C, 1.5 MPa	41.8	59.1
8	C/Cu	Zn	500 ˚C, 3 MPa	38.0	47.8
9	C/Cu	Sn	400 ˚C, 1.5 MPa	44.5	33.1
10	C/Cu	Sn	400 ˚C, 3 MPa	46.2	31.4

4. CONCLUSION

The article presents a comprehensive study of the possibilities and effects of saturating carbon and carbon-zinc composites with zinc and tin, dedicated for new generation of railway contact strips. Tests of electrical and mechanical properties have shown that use of pressure infiltration with liquid metals, such as Zn and Sn, of carbon and carbon-metal composites in a protective atmosphere allows for significant increase in strength properties and lowering of material resistance, which is advantageous for their use in railway overhead traction.

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