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TRIBOLOGICAL PROPERTIES OF MATERIALS DESIGNED FOR CONTACT WIRE / CURRENT COLLECTOR SLIDER CONTACTS

WŁAŚCIWOŚCI TRIBOLOGICZNE MATERIAŁÓW NA SKOJARZENIA PRZEWÓD TRAKCYJNY / ŚLIZGACZ ODBIERAKA PRĄDOWEGO

Key words: composite material, bronze matrix, glassy carbon, solid lubricant, cell foam, current collector.

Abstract: The article describes basics of production as well as a structure and tribological properties of a composite with a B101 bronze matrix and glassy carbon acting as a solid lubricant. The composite is intended for use as a sliding cover of a current collector in a rail transport. It is intended to replace the previously used carbon-copper composites, which have insufficient mechanical properties for high-speed rail. The results of comparative tribological tests of the matrix and composite material in contact with a traction copper (Cu-ETP) confirmed lower wear of the composite than that of the matrix under friction in air, without current load. The addition of 10% of a large-cell glassy carbon foam (90% porosity) reduced the wear of the contact (by 28% and 10%) but did not significantly reduce (by 8.4–5.8%) the friction forces. In the tested contacts abrasive and adhesive wear, caused by the presence of copper, dominated. Self-mated materials tend to develop adhesive bonds. Therefore, the next stage of the research optimising a composite production process, e.g. by using a glassy carbon foam with smaller elementary structure or glassy carbon microparticles will be used.

Słowa kluczowe: materiał kompozytowy, osnowa z brązu, węgiel szklisty, smar stały, pianka wielkokomórkowa, odbierak prądowy.

Streszczenie: W artykule opisano podstawy wytwarzania, budowę i właściwości tribologiczne kompozytu z osnową z brązu B101 i węglem szklistym pełniący rolę smaru stałego. Kompozyt jest przewidziany do zastosowania jako nakładka ślizgowa odbieraka prądowego w transporcie szynowym. Ma on zastąpić stosowane dotychczas kompozyty węglowo miedziane, które mają niewystarczające właściwości mechaniczne dla kolei wysokich prędkości. Wyniki porównawczych badań tribologicznych materiału osnowy i kompozytu we współpracy z miedzią trakcyjną (Cu-ETP) potwierdziły mniejsze zużycie kompozytu niż osnowy w warunkach tarcia technicznie suchego, bez obciążenia prądowego. Dodanie 10% wielkokomórkowej pianki (porowatość 90%) z węgla szklistego zmniejszyło zużycie skojarzenia (o 28% i 10%), ale nie zmniejszyło znacząco (o 8.4–5.8%) sił tarcia. W badanych skojarzeniach dominowały zużywanie ścierne i adhezyjne spowodowane obecnością miedzi. Materiały jednoimienne mają skłonność do sczepień adhezyjnych. Dlatego w następnym etapie badań zostanie wykorzystana optymalizacja procesu wytwarzania kompozytu, np. przez zastosowanie pianki z węgla szklistego o mniejszych wymiarach elementarnej komórki struktury oraz mikrocząstek węgla szklistego.

INTRODUCTION

A significant part of transport services, both passenger and goods, uses rail transport, i.e. trains and trams. In some cities there are electrically powered buses called trolleybuses. Electricity is supplied to them from traction wires (contact wires) via current collectors sliding on them. There are many drive solutions, including lifting and pressing a current collector (according to the

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standard [**L. 1, 2**], it is a device used for a movable contact connection of one or more contact wires) to the contact wires. However, each of these solutions requires a slider (sliding pad) that receives the current. The slider pad operates in under conditions of sliding friction in the presence of a strong electromagnetic field, sometimes an arc discharge resulting from the flowing current. The pressure forces of the slider on the contact wire depend on the height of the wire lifting (70–110 N, 300 N for high-speed railways – changing periodically, sometimes in shocks). The relative speed depends on the vehicle speed (1.7-33 m/s for PKP [**L. 3**] and up to 92 m/s for high-speed rail [**L. 4**]). High supply voltage (1.5 KV 3 kV, 15 kV, 25 kV) results in currents above 200 A and operating temperatures up to 240°C. Such working conditions require a selection of pairs of materials that ensure, among others: low frictional resistance and wear, and prevent cracking and chipping of the overlays. The wear of the contact results in the need to monitor the track infrastructure and replace traction cables and overlays when their wear exceeds the permissible values. Failure to comply with this condition may result in traction failures that disturb the conditions for carrying out transport tasks. The wear products of this contact are emitted into the environment, causing its pollution. Applicable European standards [**L. 1, 2**] define the collector components, the conditions they must meet, and the materials from which they should and can be made. These standards recommend the use of slider covers made of carbon and impregnated carbon, allow the use of copper (requiring contact lubrication [**L. 5**]) and its alloys, and other materials, provided that their properties are not worse than those of the recommended materials. In the available articles in this field [**L. 3–10**], one can find information on the materials used for current collector covers. They can be made of wire copper (M1E) or fire-refined copper, silicon-manganese steel, metallized carbon (Cu), hard carbon or a copper- and iron-based sinter.

Overlay materials must be resistant to heating [**L. 5, 6**] and meet the requirements regarding current carrying capacity. Copper overlays require coating with a layer of graphite grease, which reduces resistance and friction (friction force 17–20 N).

The carbon-copper composite overlays are not very resistant to dynamic loads and crack and chip at the edges, e.g. as a result of a contact with icy contact wires. Their brittleness causes accelerated wear when the overlays are installed incorrectly (detachment, local wear) and thermal wear of graphite during an electric arc [**L. 5**].

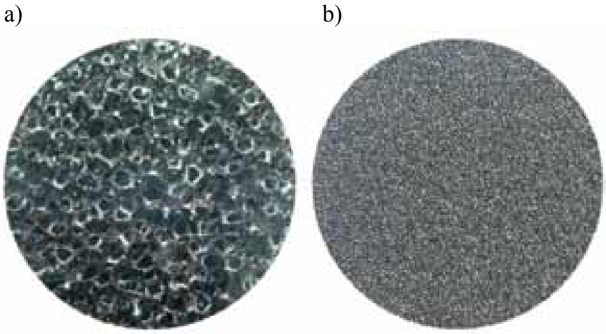

Fig. 1. Activated large- (a) and fine- (b) cell glassy carbon foam before pouring with matrix alloy

Rys. 1. Aktywowana wielkokomórkowa (a) i drobnokomórkowa (b) pianka z węgla szklistego przed zalaniem stopem osnowy

Today's materials engineering allows the production of composite materials whose properties depend on the properties of the components, i.e. the matrix and the reinforcing phase, and on the fractions of these components [**L. 7–10**]. At the Faculty of Materials Engineering and the Faculty of Transport and Aviation Engineering of the Silesian University of Technology, an attempt was made to check the suitability of composites with a B101 bronze matrix for current collector covers. This article will present the results of preliminary tribological tests of a composite with a bronze matrix and a glassy carbon (solid lubricant) intended for the sliding pads of current collectors. The material was developed in a cooperation with an industrial partner.

MANUFACTURE OF COMPOSITE

The composite was made in accordance with a patent application [**L. 11**], i.e. a large-cell (large dimensions of the elementary cell of the structure) activated a glassy carbon foam (**Fig. 1a**) with a porosity of 90% was placed in a cylindrical mold and poured with a liquid bronze B101 (CuSn10P). Discs (ϕ45x 6 mm, **Fig. 2**) were made from the obtained casting. The working surfaces of the discs were ground with 500 grit sandpaper. At the request of the industrial partner, B101 bronze was used as the matrix due to its properties and use in wear-resistant contacts operating under periodically variable or impact loads in corrosive conditions.

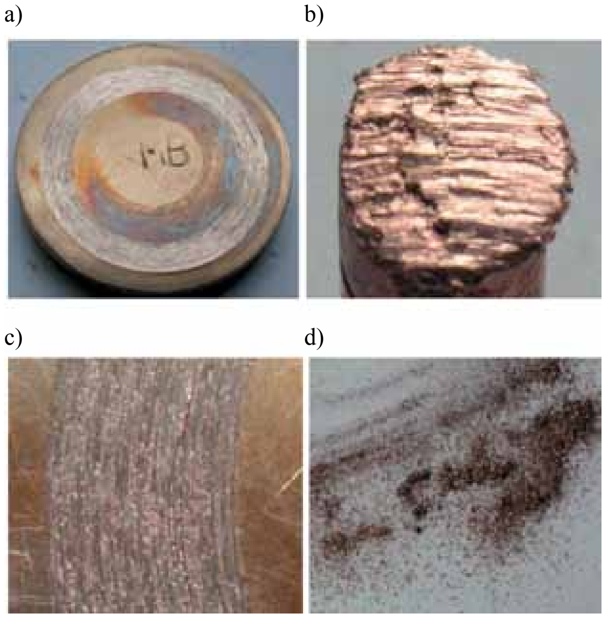

Fig. 2. Composite matrix disc (a), Cu-ETP pin (b), friction track (c) and wear debris (d) after sliding

Rys. 2. Tarcza z osnowy kompozytu (a) i trzpień Cu-ETP (b) oraz ślad współpracy (c) i produkty zużycia (d) po tarciu

CONDITIONS AND COURSE OF TESTS

The produced composite material was subjected to tribological tests to determine a coefficient of friction and wear. Tests were made of the composite in sliding against a traction cable material (a traction copper – Cu-ETP) without the use of an electric current. For comparison, a traction copper pin was tested in cooperation with the currently used overlay made of a composite with a graphite matrix (SliComp). The tests were performed on the T-01M tester with a pin on disc friction contact. The pins (ϕ=5 mm) are made of traction copper and the discs (ϕ=45 mm) are made of composite.

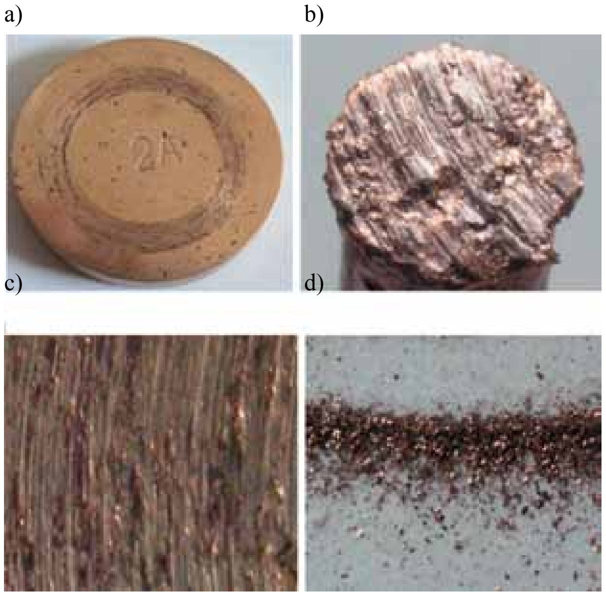

Fig. 3. Disc of composite (a) and Cu-ETP pin (b), friction track (c) and wear debris (d) after sliding

Rys. 3. Tarcza kompozytowa (a) i trzpień z Cu-ETP (b) oraz ślad współpracy (c) i produkty zużycia (d) po tarciu

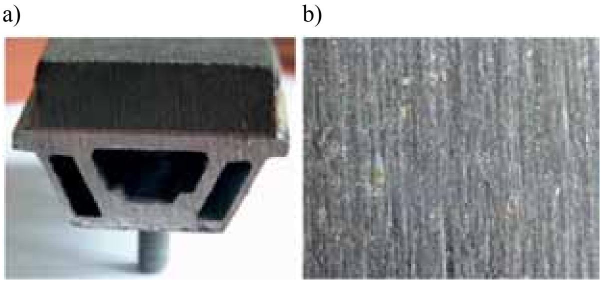

Fig. 4. Current collector made of graphite reinforced with copper (a) and its friction surface (b)

Rys. 4. Odbierak prądowy wykonany z grafitu zbrojonego miedzią (a) i jego powierzchnia ślizgowa (b)

Table 1. Results of tribological tests

Tabela 1. Wyniki badań tribologicznych

Contact	Δm_D mg	Δm_D Decrease %	Δm_P mg	Δm_P Decrease %	μ	μ Decrease %
Cu-ETP / B101+GC	496	28	619	10	0.33–0.32	8.4–5.8
Cu-ETP / B101	690		687		0.36–0.34	
Cu-ETP / SliComp.	2.1		0.1		0.1–0.07	

The relative speed (v = 2 m/s) and pressure (p = = 2 MPa) were selected based on the recommendations of the standard [**L. 1**] and the requirements of the industrial partner. The tests of contacts with the developed composite and the reference material (Cu+graphite) were repeated three times.

RESEARCH RESULTS AND THEIR DISCUSSION

During tribological tests, friction forces were measured using a force transducer working with a Spider 4 recorder with an inaccuracy of 3%. The mass loss of pins and discs was determined using a HM-3000 laboratory scale with an inaccuracy of 0.2 mg.

The results are summarized in **Table 1** (average wear from 3 contacts) and **Figures 2–6**. After tribological tests, the composite friction surfaces were subjected to macroscopic (x8) and scanning microscopic observations in order to explain the wear mechanisms. Selected results are presented in **Figures 7–8**.

In addition to the mass losses of samples and counter-samples, the table shows the percentage decreases in losses (Δm_p Decrease) in contact with the composite in relation to losses in contact with the matrix. A percentage decrease in the friction coefficient (μ Decrease) has also been added.

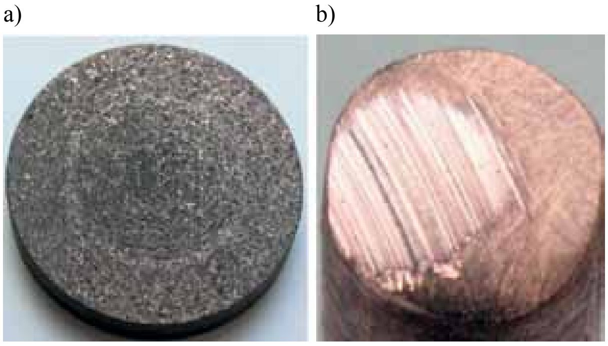

Fig. 5. Graphite disc reinforced with copper made of current collector (a) and pin of Cu-ETP (b) after sliding

Rys. 5. Tarcza z grafitu zbrojonego miedzią wykonana z kolejowego odbieraka prądu (a) i trzpień z Cu-ETP po tarciu (b)

Based on the analysis of the mass loss values (**Table 1**) of the tested contacts, it can be seen that adding 10% of a glassy carbon in the form of an open-cell foam to B101 bronze reduces its wear by approximately 28% and the wear of the pin made of a traction copper by approximately 10%. The friction coefficient at the beginning of sliding decreases by about 8.4% and at the end by about 5.8%.

The contacts of the matrix material and the composite with traction copper is dominated by intense abrasive wear (**Figs. 2, 3**), much greater than that of the material of the currently used slider. The working surfaces of the pins made of Cu-ETP deform plastically with visible traces of adhesive bonding (**Fig. 2b and 3b**). This is a result of joining identical materials (Cu in the disc and in the pin). Adding 10% GC foam is not enough to effectively separate the surfaces of the sliding parts.

Based on the analysis of the chemical composition of the composite surface after friction, it can be said that the measured amount of GC in the friction zone is small (small peak C in **Fig. 8b**). In point 1 (**Fig. 8a**), the carbon foam elements were obscured by frictionally deposited wear products (large and small Cu peaks in **Fig. 8b**). In other points, the recorded amounts of carbon do not exceed the detector's sensitivity threshold (**Fig. 8c**). Tin coming from bronze, thanks to its low shear strength, also covers the friction surface of the composite (**Figs. 8b** and **8c**). This is an additional factor that increases friction forces. During sliding cooperation, an elastic deformation of the copper pins occurred, which resulted in a reduction of the contact area (**Fig. 5b**).

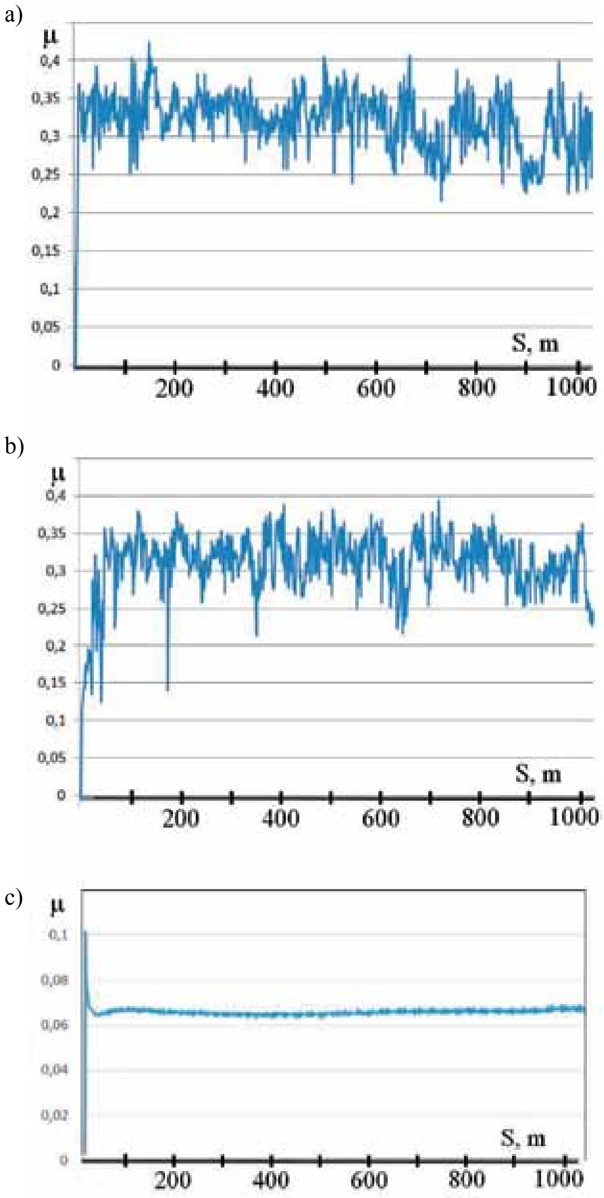

Fig. 6. Friction coefficient (μ) vs. sliding distance (S) in contact with matrix (a), composite (b) and current collector (c) material

Rys. 6. Współczynnik tarcia (μ) w funkcji drogi tarcia (S) w skojarzeniu z osnową (a), kompozytem (b) i stosowanym odbierakiem prądu (c)

Since the linear wear of the pins sliding against the tested composite (**Fig. 3b**) and its matrix (**Fig. 2b**) was greater than that of the pins sliding against the reference material (**Fig. 5b**), the traces of friction are visible on the entire friction surface.

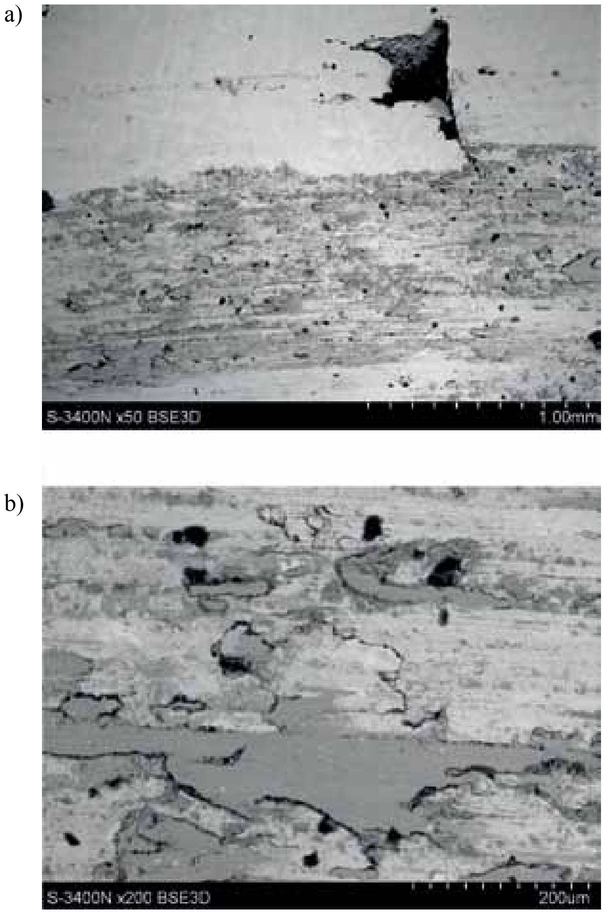

Fig. 7. Surface view from composite disc at the sliding trace border (a) and in the middle of the wear truck (b)

Rys. 7. Widok powierzchni kompozytu na granicy śladu tarcia (a) i na środku śladu tarcia (b)

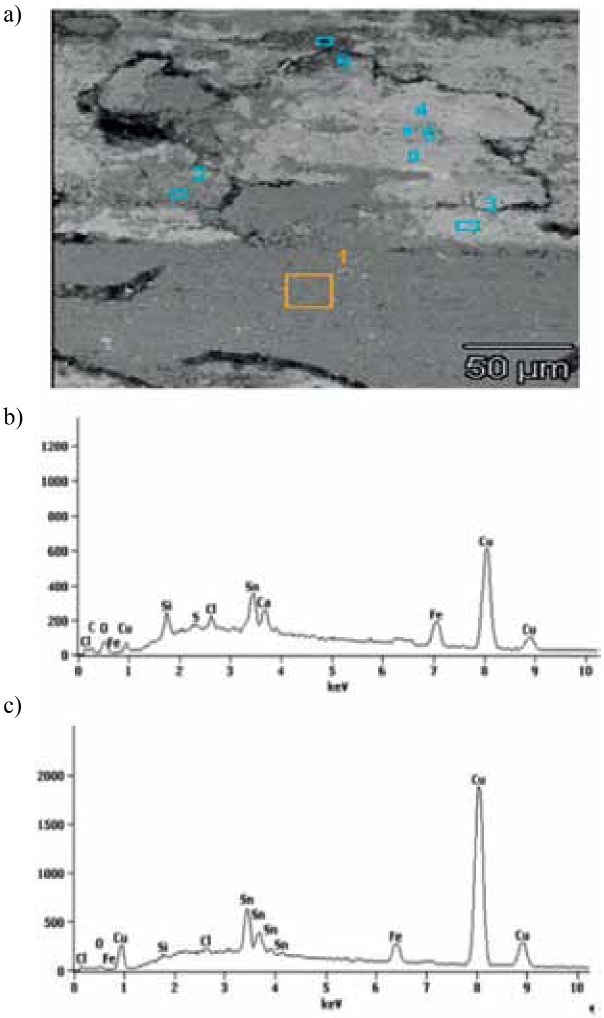

Fig. 8. Chemical composition of the tested material (b-c) at selected points (a)

Rys. 8. Skład chemiczny badanych materiałów (b-c) w wybranych punktach (a)

SUMMARY

The obtained tribological test results exclude the use of B101 bronze in the delivered state (without heat treatment) as a composite matrix intended for the sliding pads of current collectors. The composite requires optimization of technological research in order to reduce wear and the friction coefficient. Based on the analysis of the results of previous research by the authors [**L. 12–14**], it is envisaged to use a fine-cell GC foam and increase the GC content, and use GC microparticles instead of a foam. The foams used are characterized by a large cell window diameter, ranging from 0.8 to 1.3 mm, which corresponds to the porosity scale expressed as PPI 20 (pore per inch). The cell wall thickness and the average value of the distance between the carbon reinforcement elements are 0.25 and 0.7 mm, respectively. This means that the surface fraction of a glassy carbon foam in the composite is only 3%. Therefore, both the large distances and the small wall thickness of the cell window do not provide a sufficiently large contact surface between the Cu pin and the GC foam. This makes it difficult to create continuous carbon layer bonded to the substrate on the composite surface, which reduces the adhesive interaction between the materials cooperating in the sliding contact. A continuous layer of glassy carbon wear products will not be created between the sliding materials, acting as a solid lubricant, limiting wear processes and achieving an appropriately low value of the friction coefficient.

Compared to the graphite-copper composite used so far for current collectors, both the wear and the friction coefficient of the developed composite are insufficient. However, its mechanical properties are much better than those of the reference material (a tendency to crack and break off edges while driving), therefore, research will be carried out to improve the tribological properties by using glassy carbon foams with a smaller diameter and distance between the walls, which determine the formation of a layer of a solid lubricant on the contact surface of the cooperating materials.

In the contact of a traction copper with a graphite-copper composite, abrasive wear of the disc (**Fig. 5a**) and pin (**Fig. 5b**) dominates, without a participation of adhesive bonding. Therefore, the friction coefficient (**Fig. 6c**) is stable and lower than in the contacts of the matrix material (**Fig. 6a**) and the composite (**Fig. 6b**).

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