

TITLE: LOW RESISTIVITY MATERIALS WITH IMPROVED WEAR PERFORMANCE FOR ELECTRICAL CURRENT TRANSFER AND METHODS FOR PREPARING SAME

5 FIELD OF THE INVENTION

The present invention relates to a low resistivity material with improved wear performance for electrical current transfer and methods for preparing same.

In a particular non-limiting aspect, the invention relates to a copper-graphite composite material prepared by a powder metallurgy (P/M) route which shows
10 improved electrical conductivity compared with conventional copper-graphite composite materials, while maintaining higher density than other similarly prepared materials. It also relates to devices and systems including such composites.

BACKGROUND OF THE INVENTION

Carbon composite materials for use in applications such as brushes and contact
15 materials in light rail systems are known. The preparation of these materials may be via P/M techniques. However, currently available materials tend to exhibit either low conductivity or cause excessive wear of counterpart components.

The present invention seeks to provide materials and methods of preparing same which are directed to ameliorating these difficulties significantly.

20 DISCLOSURE OF THE INVENTION

According to one aspect of the present invention, there is provided a copper-graphite composite material comprising a copper network matrix having a plurality of pores therethrough, at least some of the pores containing graphite.

According to another aspect of the present invention, there is provided a
25 copper-graphite composite material having an IACS value of at least about 40% more preferably, 45%, and a density of at least about 6.0g/cm³.



Preferably, the composite materials have a density in the range of from about 6.3 to 7.6/cm³.

The microstructure of the composite material prepared in accordance with the invention has pores and contains graphite islands in a copper network matrix.

- 5 The following explanation of the way in which the invention provides improved performance is offered as a likely mechanism. The invention is not dependent on, nor is it limited by the explanation.

The composite materials according to the invention advantageously exhibit a self lubricating function resulting from the formation of a transfer graphite layer onto the
10 surface of a counterpart component. The self- lubricating function of the copper-graphite composite material effectively protects the counterpart, and thus extends the lifetime of the counterpart. This may advantageously be effective in protecting and extending the lifetime of, for example, railway electrical power transmission systems. More particularly, it is estimated that the lifetime in such an
15 application may be extended by as much as three times relative to currently used materials.

Thus the invention provides in one aspect a material which can be mounted on a pantograph for a railway train such as a pole shoe which includes a copper-graphite composite as hereinafter described as an electrical contact for receiving power from
20 overhead power lines. It also includes power transmission systems using such a composite.

In a preferred embodiment the IACS value of the composite material is at least 60%. As will be understood by a person skilled in the art, the IACS percentage is the standard conductivity (resistivity) used to judge a material's property of conduction
25 based on the International Annealed Copper Standards (IACS).

According to the invention the materials may be prepared by mixing and compacting copper and graphite powders under certain conditions, and then sintering the compacted materials. The various steps of the process may suitably be carried out under non-oxidising conditions, such as under a reducing atmosphere.

- 30 According to a further aspect of the invention there is provided a method of preparing a copper-graphite composite material comprising the steps of:



mixing a copper powder and a graphite powder under conditions to substantially prevent oxidation of the copper powder; and

5 pressing the mixture under conditions which result in the formation of a copper network matrix having a plurality of pores therethrough at least some of the pores containing graphite, wherein the copper powder has a varying particle size of no greater than about 10 μ m, and wherein the graphite powder has a particle size of no greater than about 5 μ m.

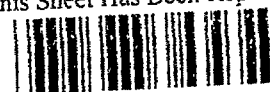
The conditions may include compacting the well mixed powders using a pressure in the range of from about 500 to about 1600 Mpa. They may also include sintering the
10 compacted powder in the form of compacts at a temperature in the range of from 960°C to 1100°C for a predetermined period under an atmosphere of H₂ and N₂

Alternatively the process may include any other process of heating and pressing such as, for example hot isostatic pressing (hipping), isolated hot pressing (IHP) or vacuum sintering.

15 The compaction of the copper and graphite powders following the mixing step is preferably performed by either two-directional compacting or dynamic compacting. When two-directional compacting is employed, a compressing pressure of from about 500 to about 1600 Mpa is applied preferably for a period of from about 5-10 Minutes. The alternative to this is dynamic compacting. When dynamic
20 compacting is employed, the shock frequency is preferably in the range of from about 150 to 250 Hz. Such a shock frequency will achieve a similar result to the application of a constant pressure as described above for the two-directional compacting method.

The copper powder used is advantageously of commercial grade purity or better, and
25 is preferably of about 99.9% purity. The varied particle size of the copper powder facilitates the optimisation of the "particle size effect" on mixing of the copper and graphite powders. For example, copper powder may be used at sizes of 10 micrometers (about 600 mesh) and 40, 150, 200 and 400 mesh. Preferably, the particle size of the copper powder ranges between about 5 micrometers and about
30 150 mesh.

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The copper powder is advantageously such that oxides and thinly oxidised films are not present on the particle surfaces. As such, in a preferred embodiment the copper powder, prior to mixing with the graphite powder, is cleaned and annealed in a controlled atmosphere which is reducing, such as a mixture of hydrogen and
5 nitrogen. Other suitable reducing atmospheres may include carbon monoxide, hydrogen, water reformed natural gas, reducing endothermic or exothermic natural gas mixtures and/or mixtures of these with less reactive gases such as nitrogen. Preferably, this is conducted at a temperature of from about 600°C to about 850°C. It will be readily understood by those skilled in the art that the temperature for
10 cleaning and annealing will depend substantially on the particle size of the copper powder.

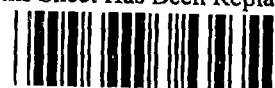
The copper powder may also have been treated to remove unwanted impurities. A magnetic separation step may be used for this purpose. Alternatively or additionally, lighter non-magnetic materials may be removed by processes such as electrostatic or
15 centrifugal separation.

The graphite powder should preferably have a particle size of no greater than about 5µm and preferably has a particle size in the range of from about 1µm to about 2µm. In a preferred embodiment the graphite powder is electro-grade quality.

As is the case in known P/M processes, other metallurgical powders may be included
20 as additives. These may include, for example, Zn, MoS₂ and Si. (Note: the Si additive may be in the form of a silicate.)

As described above, the mixing of the copper and graphite powders is performed under conditions to prevent oxidation of the copper powder. Preferably, the powder mixing is performed at a relatively slow speed, such as about 150 rpm in a
25 conventional mill.

As discussed above, the compacting of the mixed powder is advantageously performed by a two-directional compacting method or a dynamic compacting method. The upper compression pressure of about 1600 Mpa, which may be used in accordance with the present invention is substantially higher than that conventionally
30 used in P/M techniques. This is generally about 690 Mpa. It is worth noting that the pressure here is defined as load/cross sectional area of the compacting die.



The sintering temperature of the sintering step may be in the range of from about 960°C to about 1100°C. The holding time in the furnace will depend on the furnace facilities as would be readily understood by those skilled in the art. The reducing atmosphere used in the sintering step preferably consists of 10% H₂ and 90% N₂ and provides an exothermic atmosphere in the furnace.

It will be understood that the above process is provided for exemplification only as a preferred method of forming the composite materials of the invention. Other methods may also be employed provided that these produce a composite material having the advantageous characteristics as described herein.

10 BRIEF DESCRIPTION OF THE ILLUSTRATION

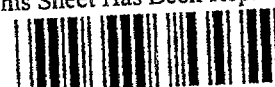
Figure 1 illustrates the typical microstructure of a copper-graphite composite material prepared in accordance with the invention. As can be seen from the figure, the copper phase has dispersed therein a number of large pores enclosing graphite islands. As mentioned above, this network of copper with graphite dispersed throughout advantageously provides a substantial improvement in the electrical conductivity of the composite material, and also advantageously supplies graphite which forms a lubricating carbonaceous film between the moving parts, i.e. the current collectors (contact material) and the electrical contact wires.

Particular embodiments of the present invention will now be described with reference to the following examples. The examples are provided for exemplification only and should not be construed as limiting on the invention in any way.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following table provides more detailed information on particular embodiments of the composite material prepared in accordance with the invention in terms of chemical composition, physical properties, heat capacities, electrical properties and tribological properties.

The samples in Table 1 were prepared in accordance with the methods described hereinbefore, ie the copper powder having a range of particle sizes of 10μ, 40, 150, 220 and 400 mesh was cleaned by electrostatic and magnetic separation. It was then annealed in a reducing atmosphere of 10% hydrogen and 90% nitrogen. The



annealed copper powder was mixed with other powder components, of which the graphite powder had a particle size range of 1 μ m to 2 μ m. The mixture was compacted using a two-directional compacting or dynamic compacting approach and the compacted mixture in the form of a compact was sintered for about two hours in a reducing atmosphere at 10% hydrogen and 90% nitrogen. The sintering temperature was in the range 960°C to 1100°C.

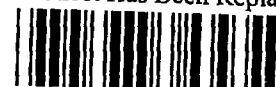
1) Nominal chemical compositions are given in Table 1.

Table 1

Sample No.	Weight proportion in initial mixture (%)					C.G.C.M. suggested name
	Cu	Graphite	Zinc	MoS ₂	Silicate	
1	92.0	7.0	-	0.5	0.5	CuGMnSi
2	89.0	10.0	-	-	1.0	CuGSi
3	87.0	11.0	1.5	-	0.5	CuG12ZnSi
4	85.0	15.0	-	-	-	CuG
5	82.0	17.5	-	-	0.5	CuGSi
6	68.0	27.0	2.0	1.5	1.0	CuGZnMoSi
7	80.0	15.0	-	5.0	-	CuG15Mo
8	78.0	16.5	-	5.0	0.5	CuG16Mo5Si
9	75.0	15.0	-	10.0	-	CuG15Mo10
10	70.0	23.5	2.5	4.0	-	CuG23Mo4Zn

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- 2) Some measured physical properties are given in Table 2:

Table 2

Sample No.	Density (gr/cm ³)	Max Operation Temperature (°C)	Melting point (°C)	Coefficient of thermal expansion (x10 ⁻⁶ /°C)	Thermal conductivity (W/m-°K)
1	6.984	<u>450</u>	1085	17.30	<u>366</u>
2	7.049	<u>450</u>	1085	16.34	354
3	7.545	<u>470</u>	1085	16.02	<u>346</u>
4	6.372	<u>470</u>	1085	15.82	<u>338</u>
5	6.656	<u>480</u>	1085	15.72	<u>326</u>
6	6.163	<u>480</u>	1100	<u>10.65</u>	<u>271</u>
7	7.119	<u>480</u>	1100	<u>14.48</u>	<u>318</u>
8	6.837	<u>480</u>	1100	<u>13.50</u>	<u>310</u>
9	6.370	<u>480</u>	1100	<u>12.24</u>	<u>299</u>
10	6.300	<u>480</u>	1100	<u>11.56</u>	<u>278</u>

- 5 suggested temperature beyond which it is estimated that the properties deteriorate rapidly.

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3) The heat capacities* of CGCM are given in Table 3, as calculated from thermodynamic data.

Table 3

Sample No.	a	b $\times 10^3$	c $\times 10^3$	Temp. range($^{\circ}$ K)
1	5.285	1.388	-0.158	298 ~ 1.356
2	5.225	1.437	-0.210	298 ~ 1.356
3	5.207	1.431	-0.252	298 ~ 1.356
4	5.214	1.428	-0.315	298 ~ 1.356
5	5.154	1.409	-0.368	298 ~ 1.356
6	4.973	1.379	-0.567	298 ~ 1.356
7	5.211	1.473	-0.315	298 ~ 1.356
8	5.165	1.458	-0.347	298 ~ 1.356
9	5.064	1.429	-0.378	298 ~ 1.356
10	5.039	1.415	-0.504	298 ~ 1.356
Copper	5.410	1.500	-	298 ~ 1.356

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*Note: $C_p = a + bT + cT^2$ (Cal/ $^{\circ}$ K mole)

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- 4) Compacting stress and mechanical properties are given in Table 4.

Table 4

Sample No.	Compacting stress (Mpa)	Compress strength (Mpa)	Modulus of elasticity (Mpa)	Ductility (EL in 1.5 in) (5)	Possion's ratio	Vickers hardness (VH)
1	523	200	87	<u>20</u>	<u>0.32</u>	78 ~80
2	523	185	78	<u>18</u>	<u>0.28</u>	68~86
3	523	172	60	<u>18</u>	<u>0.26</u>	60~69
4	523	175	54	<u>20</u>	<u>0.20</u>	60~79
5	523	167	39	<u>17</u>	<u>0.31</u>	80~90
6	523	105	28	<u>17</u>	<u>0.21</u>	65~72
7	523	150	42	<u>15</u>	<u>0.15</u>	70~89
8	523	140	35	<u>14</u>	<u>0.18</u>	75~82
9	523	138	32	<u>14</u>	<u>0.12</u>	86~92
10	523	120	30	<u>12</u>	<u>0.13</u>	58~67

Note: Underlined data are estimated values based on calculation of composite

- 5 materials properties – ASM, Metals Handbook, - Composite Materials.

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- 5) Electrical properties of these materials were measured and are given in Table 5.

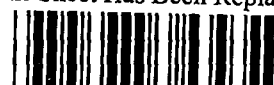
Table 5

Sample No.	Percentage of IACS* (%)	Operating Voltage (V)	Resistivity ($\mu\Omega\text{cm } 20^{\circ}\text{C}$)	Max. current density (amp/mm ²)
1	65.8	600	5.05	<u>18</u>
2	76.4	600	4.74	<u>20</u>
3	59.0	600	6.14	<u>16</u>
4	69.0	600	5.25	<u>15</u>
5	67.2	600	5.39	<u>15</u>
6	46.8	600	7.74	<u>14</u>
7	64.6	600	5.60	<u>13</u>
8	42.9	600	8.24	<u>13</u>
9	6.19	600	5.85	<u>12</u>
10	43.0	600	8.42	<u>10</u>

- 5 *Note 1:* The percentage of IACS is the standard conductivity (resistivity) used to judge the material's property of conduction, and is based on the International Annealed Copper Standard (IACS) adopted by IEC in 1913, which states that $1/58 \Omega \text{ mm}^2/\text{m}$ and the value of $0.017241 \Omega \text{ gm mm}^2/\text{m}$ and the value of $0.15328 \Omega \text{ gm}/\text{m}^2$ at 20°C (68°F) are, respectively, the international equivalent of
- 10 volume and weight resistivity of annealed copper equal to 100% conductivity.

Note 2: Underlined data are estimated values. The current capacity is calculated from the electrical current which can pass through 1 mm^2 area of material with no damage to that area at maximum operational temperature.

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6. Tribological properties

Table 6

Sample No	Wear Factor ($\times 10^{-4} K$)	Wear Rate (α)	Coefficient of friction (μ)	Layers transferring rate** ($10^{-7} A/m$)
1	1.64	9.23	0.25	3.13
2	1.75	9.17	<u>0.22-0.26</u>	
3	1.43	9.32	<u>0.25</u>	4.19
4	2.56	14.60	<u>0.22-0.26</u>	
5	1.17	5.87	<u>0.20-0.24</u>	
6	1.69	10.50	<u>0.18-0.21</u>	
7	1.28	7.97	0.22	2.97
8	1.30	7.16	<u>0.18-0.21</u>	
9	9.38	45.90	0.18	3.59
10	10.78	52.70	0.18	6.23

*Note 1: The tribological properties were measured under the conditions of normal load – 13.5N, sliding velocity 0.25m/sec and the counterpart metal is pure copper contact wire (after 10^8 wear cycles).

Note 2: Double underlined data were obtained on undefined metal (copper) surfaces before wear test.

Note 3 (**): The data for rate transfer was measured using a specially designed testing device.

- 10 The following table summarises the relevant properties of other materials containing copper and carbon prepared by conventional P/M techniques. It is worth noting that the highest conductivity listed in the table is just above 40% IACS, with the majority of these values being significantly below the IACS values of composite materials prepared in accordance with the materials of the invention, 43% IACS
- 15 being the lowest value in this respect.



Table 7: Commercial materials available for use of electrical contacts

Composition (%)	Approximate density (g/cm ³)	Electrical conductivity (% IACS)	Hardness (HRB)
30Cu, 70Graphite	2.5	0.11	80
36Cu, 64Graphite	2.75	3	75
40Cu, 60Graphite	2.75	4	52
50Cu, 50Graphite	3.05	2.5	35
62Cu, 38Graphite	3.65	3	28
65Cu, 35Graphite	3.15	3	30
75Cu, 25Graphite	3.25	0.51	21
92Cu, 8Graphite	7.30	41	40
95Cu, 5Graphite	6.30	34	38
96Cu, 4Graphite	7.75	42	40
21Cu, 79C	2.2	0.25	28
35Cu, 65C	2.5	2	28
50Cu, 50C	2.75	5	28
65Cu, 35C	3.5	8	20B
75Cu, 25C	4.0	21	18
95Cu, 5C	7.57	40-46	38HR15-T

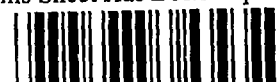
It is envisaged that the composite materials of the invention may be used as contact brushes for electrical motors, pantographs and pole shoes for light rail applications, power generators and other electrical components such as switches, etc.

Furthermore, the particular method of production described above is advantageously relatively simple and economical.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and

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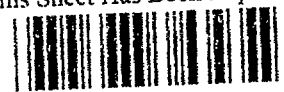
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"comprising", will be understood to imply the inclusion of a stated integer or group of integers or steps but not the exclusion of any other integer or group of integers or steps.

Those skilled in the art will appreciate that the invention described herein is
5 susceptible to variations and modifications other than those specifically described. It is to be understood that the invention includes all such variations and modifications. The invention also includes all of the steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively, and any and all combinations of any two or more of said steps or features.

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CLAIMS

1. A copper-graphite composite material comprising a copper network matrix having a plurality of pores therethrough, at least some of the pores containing graphite.
- 5 2. A copper-graphite composite material having an IACS value of at least about 40% and a density of at least about 6.0 g/cm^3 wherein the microstructure of the composite material is such that it contains graphite islands in a copper network matrix.
3. A copper-graphite composite material according to claim 2 which includes a
10 proportion of additives chosen from any one or more of Zn , MoS_2 and Si .
4. A copper-graphite composite material according to claim 2 wherein the weight percentage proportion of copper in the composite is at least 68%.
5. A copper-graphite composite material according to claim 2 having a density in the range from about 6.3 g/cm^3 to about 7.6 g/cm^3 .
- 15 6. A copper-graphite composite material according to claim 5 having an IACS value of at least 45%.
7. A copper-graphite composite material according to claim 2 wherein the composite has been formed by mixing, compacting and sintering mixtures of copper and graphite powders and the copper powder is about 99.9% purity.
- 20 8. A copper-graphite composite material according to claim 2 wherein the composite has been formed by mixing, compacting and sintering mixtures of copper and graphite powders and the copper powder is sized in the range 5 micrometers and about 10 mesh.
9. A copper-graphite composite material according to claim 8 wherein the
25 copper powder is sized in the range 10 micrometers and about 400 mesh.
10. A copper-graphite material according to claim 2 wherein the composite has been formed by mixing, compacting and sintering mixtures of copper and graphite powders and the copper powder has been cleaned and annealed in a controlled atmosphere prior to mixing.



11. A copper-graphite material according to claim 10 wherein the graphite powder size is no greater than about 5 micrometers.
12. A method of preparing a copper-graphite composite material comprising the steps of:
 - 5 mixing a copper powder and a graphite powder under conditions to substantially prevent oxidation of the copper powder;
 - compacting the mixed powder to produce a compact, and
 - sintering the compact at elevated temperature for a time sufficient to create a composite material containing graphite islands in a copper
 - 10 network matrix.
13. A method according to claim 12 wherein the compaction is two-directional and the pressure of compaction is in the range from about 500 to about 1600 MPa.
14. A method according to claim 12 wherein the temperature of sintering is in
15 the range from 960°C to 1100°C.
15. A method according to claim 12 wherein sintering is carried out in a non-oxidising atmosphere.
16. A method according to claim 15 wherein the non-oxidising atmosphere includes any one or more of carbon monoxide, hydrogen, water reformed
20 natural gas, reducing endothermic or exothermic natural gas mixtures and/or mixtures of any of these with a less reactive gas.
17. A method according to claim 14 wherein the non-oxidising atmosphere is reducing and comprises a mixture of hydrogen and nitrogen.
18. A method according to claim 12 wherein the mixed powder is dynamically
25 compacted.
19. A method according to claim 18 wherein the shock frequency of dynamic compaction is 150 Hz to 250 Hz.
20. A method according to claim 11 wherein the copper powder is cleaned and is annealed in a reducing atmosphere.



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21. A method according to claim 20 wherein the cleaning step includes any one or more of magnetic, electrostatic or centrifugal separation steps.
22. A method according to claim 20 wherein the reducing atmosphere includes any one or more of carbon monoxide, hydrogen, water reformed natural gas,
5 reducing endothermic or exothermic natural gas mixtures and/or mixtures of any of these with a less reactive gas.
23. A method according to claim 20 wherein the reducing atmosphere comprises a mixture of hydrogen and nitrogen.
24. A method according to claim 12 wherein the mixture of powders includes
10 any one or more of Zn, MoS₂ and Si.
25. A method according to claim 12 wherein the components of the copper-graphite composite are selected to provide that the composite has a density in the range from about 6.3 g/cm³ to about 7.6 g/cm³.
26. A method of preparing a copper-graphite composite material comprising the
15 steps of:
- mixing a copper powder and a graphite powder under conditions to substantially prevent oxidation of the copper powder;
- compacting the mixed powder at a pressure of from about 500 to 1600 MPa; and
- 20 sintering the compacted powder at a temperature in the range of from 960°C to 1100°C for a predetermined period under an atmosphere of H₂ and N₂;
- wherein the copper powder has a varying particle size of no greater than 10 micrometers, and wherein the graphite powder has a particle
25 size of no greater than about 5 micrometers.
27. A copper-graphite composite material when prepared by the process of claim 26.
28. A pantograph for a railway train including a copper-graphite composite material as defined in claim 2 as an electrical contact for collecting power
30 from overhead power lines.



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29. An electrical power transmission system including a pantograph as defined in claim 28 as a power collector for a railway train or tram.
30. A device for transferring electrical power between conductors moving relative to each other wherein at least one of the conductors comprises a copper-graphite composite according to claim 1.
31. A copper-graphite composite material having an IACS value of at least 40%, a density of at least 6.0 g/cm³ and a Vickers hardness of at least 58, wherein the composite material comprises a copper network matrix having a plurality of pores therethrough, at least some of the pores containing graphite.
32. A method of preparing a copper graphite composite material comprising the steps of:
- mixing a copper powder and a graphite powder under conditions to substantially prevent oxidation of the copper powder; and
- pressing the mixture of copper powder and graphite powder under conditions which result in the formation of a copper network matrix having a plurality of pores therethrough, at least some of the pores containing graphite;
- wherein the copper powder has a varying particle size of no greater than 10 μm , and wherein the graphite powder has a particle size of no greater than about 5 μm .
33. A method according to claim 32 wherein the mixture is subjected to hot isostatic pressing.
34. A copper graphite material according to claim 8 wherein the copper powder sizing is about 150 mesh.

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