0.5 atomic weight percent. The oxygen content of the graphenic carbon particles can be determined using X-ray Photoelectron Spectroscopy, such as is described in D. R. Dreyer et al., Chem. Soc. Rev. 39, 228-240 (2010).

[0009] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a B.E.T. specific surface area of at least 50 square meters per gram, such as 70 to 1000 square meters per gram, or, in some cases, 200 to 1000 square meters per grams or 200 to 400 square meters per gram. As used herein, the term "B.E.T. specific surface area" refers to a specific surface area determined by nitrogen adsorption according to the ASTMD 3663-78 standard based on the Brunauer-Emmett-Teller method described in the periodical "The Journal of the American Chemical Society", 60, 309 (1938).

[0010] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a Raman spectroscopy 2D/G peak ratio of at least 1.1, for example, at least 1.2 or 1.3. As used herein, the term "2D/G peak ratio" refers to the ratio of the intensity of the 2D peak at 2692 cm^{-1} to the intensity of the G peak at 1,580 cm^{-1}.

[0011] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a relatively low bulk density. For example, the graphenic carbon particles used in certain embodiments of the present invention are characterized by having a bulk density (tap density) of less than 0.2 g/cm^3, such as no more than 0.1 g/cm^3. For the purposes of the present invention, the bulk density of the graphenic carbon particles is determined by placing 0.4 grams of the graphenic carbon particles in a glass measuring cylinder having a readable scale. The cylinder is raised approximately one-inch and tapped 100 times, by striking the base of the cylinder onto a hard surface, to allow the graphenic carbon particles to settle within the cylinder. The volume of the particles is then measured, and the bulk density is calculated by dividing 0.4 grams by the measured volume, wherein the bulk density is expressed in terms of g/cm^3.

[0012] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a compressed density and a percent densification that is less than the compressed density and percent densification of graphite powder and certain types of substantially flat graphenic carbon particles. Lower compressed density and lower percent densification are each currently believed to contribute to better dispersion and/or rheological properties than graphenic carbon particles exhibiting higher compressed

density and higher percent densification. In certain embodiments, the compressed density of the graphenic carbon particles is 0.9 or less, such as less than 0.8, less than 0.7, such as from 0.6 to 0.7. In certain embodiments, the percent densification of the graphenic carbon particles is less than 40%, such as less than 30%, such as from 25 to 30%.

[0013] For purposes of the present invention, the compressed density of graphenic carbon particles is calculated from a measured thickness of a given mass of the particles after compression. Specifically, the measured thickness is determined by subjecting 0.1 grams of the graphenic carbon particles to cold press under 15,000 pound of force in a 1.3 centimeter die for 45 minutes, wherein the contact pressure is 500 MPa. The compressed density of the graphenic carbon particles is then calculated from this measured thickness according to the following equation:

$$\text{Compressed Density } (g/cm^3) = \frac{0.1 \text{ grams}}{\Pi*(1.3cm/2)^2*(\text{measured thickness in cm})}$$

[0014] The percent densification of the graphenic carbon particles is then determined as the ratio of the calculated compressed density of the graphenic carbon particles, as determined above, to 2.2 g/cm^3, which is the density of graphite.

[0015] In certain embodiments, the graphenic carbon particles have a measured bulk liquid conductivity of at least 100 microSiemens, such as at least 120 microSiemens, such as at least 140 microSiemens immediately after mixing and at later points in time, such as at 10 minutes, or 20 minutes, or 30 minutes, or 40 minutes. For the purposes of the present invention, the bulk liquid conductivity of the graphenic carbon particles is determined as follows. First, a sample comprising a 0.5% solution of graphenic carbon particles in butyl cellosolve is sonicated for 30 minutes with a bath sonicator. Immediately following sonication, the sample is placed in a standard calibrated electrolytic conductivity cell (K=1). A Fisher Scientific AB 30 conductivity meter is introduced to the sample to measure the conductivity of the sample. The conductivity is plotted over the course of about 40 minutes.

[0016] In accordance with certain embodiments, percolation, defined as long range interconnectivity, occurs between the conductive graphenic carbon particles. Such percolation may reduce the resistivity of the formulations. The conductive graphenic particles may occupy a minimum volume within the composite matrix such that the particles form a continuous, or nearly continuous, network. In such a case, the aspect ratios of the graphenic

WE CLAIM:

1. A rubber formulation comprising:

a base rubber composition;

from 0.1 to 20 weight percent graphenic carbon particles; and

from 1 to 50 weight percent filler particles, wherein the rubber formulation has a surface resistivity of less than 10^{10} Ω/sq.

2. The rubber formulation of Claim 1, wherein the rubber formulation comprises a tire tread formulation.

3. The rubber formulation of Claim 1, wherein the graphenic carbon particles comprise less than 10 weight percent of the formulation.

4. The rubber formulation of Claim 1, wherein the graphenic carbon particles comprise less than 5 weight percent of the formulation.

5. The rubber formulation of Claim 1, wherein the graphenic carbon particles have a bulk liquid conductivity of at least 100 microSiemens.

6. The rubber formulation of Claim 1, wherein the graphenic carbon particles have a bulk density of less than 0.2 g/cm^3.

7. The rubber formulation of Claim 1, wherein the graphenic carbon particles have a compressed density of less than 0.9.

8. The rubber formulation of Claim 1, wherein the graphenic carbon particles have an oxygen content of less than 2 atomic weight percent.

9. The rubber formulation of Claim 1, wherein the filler particles comprise silica.

10. The rubber formulation of Claim 9, wherein the silica comprises from 28 to 44 weight percent of the formulation.

11. The rubber formulation of Claim 9, wherein the graphenic carbon particles comprise less than 10 weight percent, and the silica comprises greater than 28 weight percent of the formulation.

12. The rubber formulation of Claim 9, wherein the silica and the graphenic carbon particles are present in the formulation in a weight ratio of greater than 4:1.

13. The rubber formulation of Claim 9, wherein the silica comprises precipitated silica.

14. The rubber formulation of Claim 1, wherein the base rubber composition comprises styrene/butadiene rubber, butadiene rubber, natural rubber and/or functionalized derivatives thereof.

15. The rubber formulation of Claim 14, wherein the base rubber composition comprises at least one additive selected from processing oils, antioxidants, curatives and metal oxides.

16. The rubber formulation of Claim 1, wherein the formulation comprises less than 10 weight percent carbon black.

17. The rubber formulation of Claim 1, wherein the formulation is substantially free of carbon black.

18. A method of making a rubber formulation comprising:

mixing graphenic carbon particles and filler particles with a base rubber composition; and

curing the mixture, wherein the cured mixture has a surface resistivity of less than 10^{10} Ω/sq.

19. The method of Claim 18, wherein the graphenic carbon particles comprise less than 10 weight percent of the formulation, and the filler particles comprise silica in an amount greater than 28 weight percent of the formulation.

20. The method of Claim 19, wherein the silica and the graphenic carbon particles are present in the formulation in a weight ratio of greater than 4:1.

0.5 atomic weight percent. The oxygen content of the graphenic carbon particles can be determined using X-ray Photoelectron Spectroscopy, such as is described in D. R. Dreyer et al., Chem. Soc. Rev. 39, 228-240 (2010).

[0009] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a B.E.T. specific surface area of at least 50 square meters per gram, such as 70 to 1000 square meters per gram, or, in some cases, 200 to 1000 square meters per grams or 200 to 400 square meters per gram. As used herein, the term "B.E.T. specific surface area" refers to a specific surface area determined by nitrogen adsorption according to the ASTMD 3663-78 standard based on the Brunauer-Emmett-Teller method described in the periodical "The Journal of the American Chemical Society", 60, 309 (1938).

[0010] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a Raman spectroscopy 2D/G peak ratio of at least 1.1, for example, at least 1.2 or 1.3. As used herein, the term "2D/G peak ratio" refers to the ratio of the intensity of the 2D peak at 2692 cm^{-1} to the intensity of the G peak at 1,580 cm^{-1}.

[0011] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a relatively low bulk density. For example, the graphenic carbon particles used in certain embodiments of the present invention are characterized by having a bulk density (tap density) of less than 0.2 g/cm^3, such as no more than 0.1 g/cm^3. For the purposes of the present invention, the bulk density of the graphenic carbon particles is determined by placing 0.4 grams of the graphenic carbon particles in a glass measuring cylinder having a readable scale. The cylinder is raised approximately one-inch and tapped 100 times, by striking the base of the cylinder onto a hard surface, to allow the graphenic carbon particles to settle within the cylinder. The volume of the particles is then measured, and the bulk density is calculated by dividing 0.4 grams by the measured volume, wherein the bulk density is expressed in terms of g/cm^3.

[0012] In certain embodiments, the graphenic carbon particles used in the compositions of the present invention have a compressed density and a percent densification that is less than the compressed density and percent densification of graphite powder and certain types of substantially flat graphenic carbon particles. Lower compressed density and lower percent densification are each currently believed to contribute to better dispersion and/or rheological properties than graphenic carbon particles exhibiting higher compressed density and higher percent densification. In certain embodiments, the compressed density of the graphenic carbon particles is 0.9 g/cm^3 or less, such as less than 0.8 g/cm^3, less than 0.7 g/cm^3, such as from 0.6 g/cm^3 to 0.7 g/cm^3. In certain embodiments, the percent densification of the graphenic carbon particles is less than 40%, such as less than 30%, such as from 25 to 30%.

[0013] For purposes of the present invention, the compressed density of graphenic carbon particles is calculated from a measured thickness of a given mass of the particles after compression. Specifically, the measured thickness is determined by subjecting 0.1 grams of the graphenic carbon particles to cold press under 15,000 pound of force in a 1.3 centimeter die for 45 minutes, wherein the contact pressure is 500 MPa. The compressed density of the graphenic carbon particles is then calculated from this measured thickness according to the following equation:

$$\text{Compressed Density } (g/cm^3) = \frac{0.1 \text{ grams}}{\Pi^*(1.3cm/2)^2*(\text{measured thickness in cm})}$$

[0014] The percent densification of the graphenic carbon particles is then determined as the ratio of the calculated compressed density of the graphenic carbon particles, as determined above, to 2.2 g/cm^3, which is the density of graphite.

[0015] In certain embodiments, the graphenic carbon particles have a measured bulk liquid conductivity of at least 100 microSiemens, such as at least 120 microSiemens, such as at least 140 microSiemens immediately after mixing and at later points in time, such as at 10 minutes, or 20 minutes, or 30 minutes, or 40 minutes. For the purposes of the present invention, the bulk liquid conductivity of the graphenic carbon particles is determined as follows. First, a sample comprising a 0.5% solution of graphenic carbon particles in butyl cellosolve is sonicated for 30 minutes with a bath sonicator. Immediately following sonication, the sample is placed in a standard calibrated electrolytic conductivity cell (K=1). A Fisher Scientific AB 30 conductivity meter is introduced to the sample to measure the conductivity of the sample. The conductivity is plotted over the course of about 40 minutes.

[0016] In accordance with certain embodiments, percolation, defined as long range interconnectivity, occurs between the conductive graphenic carbon particles. Such percolation may reduce the resistivity of the formulations. The conductive graphenic particles may occupy a minimum volume within the composite matrix such that the particles form a continuous, or nearly continuous, network. In such a case, the aspect ratios of the graphenic

Claims:

Claim 1. A rubber formulation comprising:

a base rubber composition;

from 0.1 to 20 weight percent graphenic carbon particles having a buckled 3D morphology; and

from 1 to 50 weight percent filler particles,

wherein said graphenic carbon particles have been prepared by introducing (i) a hydrocarbon precursor material capable of forming a two-carbon fragment species, or (ii) methane into a thermal zone having a temperature of at least 1000°C, thereby to form graphenic carbon particles, and subsequently quenching and collecting the formed graphenic carbon particles, and

wherein the rubber formulation has a surface resistivity of less than 10^{10} Ω/sq.

Claim 2. The rubber formulation of Claim 1, wherein the rubber formulation comprises a tire tread formulation.

Claim 3. The rubber formulation of Claim 1, wherein the graphenic carbon particles comprise less than 10 weight percent of the formulation.

Claim 4. The rubber formulation of Claim 1, wherein the graphenic carbon particles comprise less than 5 weight percent of the formulation.

Claim 5. The rubber formulation of Claim 1, wherein the graphenic carbon particles have a bulk liquid conductivity of at least 100 microSiemens.

Claim 6. The rubber formulation of Claim 1, wherein the graphenic carbon particles have a bulk density of less than 0.2 g/cm^3.

Claim 7. The rubber formulation of Claim 1, wherein the graphenic carbon particles have a compressed density of less than 0.9 g/cm^3.

Claim 8. The rubber formulation of Claim 1, wherein the graphenic carbon particles have an oxygen content of less than 2 atomic weight percent.

Claim 9. The rubber formulation of Claim 1, wherein the filler particles comprise silica.

Claim 10. The rubber formulation of Claim 9, wherein the silica comprises from 28 to 44 weight percent of the formulation.

Claim 11. The rubber formulation of Claim 9, wherein the graphenic carbon particles comprise less than 10 weight percent, and the silica comprises greater than 28 weight percent of the formulation.

Claim 12. The rubber formulation of Claim 9, wherein the silica and the graphenic carbon particles are present in the formulation in a weight ratio of greater than 4:1.

Claim 13. The rubber formulation of Claim 9, wherein the silica comprises precipitated silica.

Claim 14. The rubber formulation of Claim 1, wherein the base rubber composition comprises styrene/butadiene rubber, butadiene rubber, natural rubber and/or functionalized derivatives thereof.

Claim 15. The rubber formulation of Claim 14, wherein the base rubber composition comprises at least one additive selected from processing oils, antioxidants, curatives and metal oxides.

Claim 16. The rubber formulation of Claim 1, wherein the formulation comprises less than 10 weight percent carbon black.

Claim 17. The rubber formulation of Claim 1, wherein the formulation is substantially free of carbon black.

Claim 18. A method of making a rubber formulation comprising:

mixing graphenic carbon particles having a buckled 3D morphology and filler particles with a base rubber composition; and

curing the mixture,

wherein said graphenic carbon particles have been prepared by introducing (i) a hydrocarbon precursor material capable of forming a two-carbon fragment species, or (ii) methane into a thermal zone having a temperature of at least 1000°C, thereby to form graphenic carbon particles, and subsequently quenching and collecting the formed graphenic carbon particles,

wherein the cured mixture has a surface resistivity of less than 10^{10} Ω/sq.

Claim 19. The method of Claim 18, wherein the graphenic carbon particles comprise less than 10 weight percent of the formulation, and the filler particles comprise silica in an amount greater than 28 weight percent of the formulation.

Claim 20. The method of Claim 19, wherein the silica and the graphenic carbon particles are present in the formulation in a weight ratio of greater than 4:1.