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(54) **SHEAR THICKENING FORMULATION AND COMPOSITE MATERIAL EMPLOYING THE SAME**

(71) Applicant: **INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE**, Hsinchu (TW)

(72) Inventors: **Wei-Hao Lai**, Kaohsiung (TW); **Shih-Ming Chen**, Hsinchu (TW); **Cheng-Yi Lin**, Hukou Township (TW)

(73) Assignee: **INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE**, Hsinchu (TW)

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See application file for complete search history.

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Primary Examiner — John Uselding

(74) *Attorney, Agent, or Firm* — Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

A shear thickening formulation and composite material employing the same are provided. The shear thickening formulation includes inorganic particles and polyethylene glycol. The inorganic particles and the polyethylene glycol have a weight ratio of 3 to 4. The inorganic particles can be silica, aluminum oxide, silicon carbide, nano diamond, or a combination thereof.

6 Claims, No Drawings

SHEAR THICKENING FORMULATION AND COMPOSITE MATERIAL EMPLOYING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is based on, and claims priority from, Taiwan Application Serial Number 103129304, filed on Aug. 26, 2014, the disclosure of which is hereby incorporated by reference herein in its entirety.

TECHNICAL FIELD

The technical field relates to a shear thickening formulation and application thereof.

BACKGROUND

The shear thickening material can be applied in impact resistant and protective equipment. It may instantly absorb energy to be hardened to provide protection under high-speed impact. When the energy is released, the shear thickening material may recover to its original state (e.g. a moldable state), such that the shear thickening material can be widely applied in various fields. As such, accelerating the shear thickening rate or enhancing the maximum viscosity of the shear thickening material may improve the protection effect thereof.

Accordingly, developments of the shear thickening formulation with a faster shear thickening rate and protection equipment utilizing the same are important topics.

SUMMARY

One embodiment of the disclosure provides a shear thickening formulation, comprising: inorganic particles; and polyethylene glycol, wherein the inorganic particles and the polyethylene glycol have a weight ratio of 3 to 4, the inorganic particles are silicon oxide, aluminum oxide, silicon carbide, nano diamond, or a combination thereof.

One embodiment of the disclosure provides a composite material, comprising: a matrix; and the described shear thickening formulation.

A detailed description is given in the following embodiments.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details.

Shear thickening formulations and application thereof are disclosed. The shear thickening formulations may achieve their maximum viscosity at low shear rate, such that composite materials including the same may absorb impact energy while being impacted. When an object is wrapped by the composite material of the disclosure, the object can be protected by the impact resistant composite material.

The shear thickening formulations of the disclosure may include inorganic particles and polyethylene glycol (PEG), wherein the inorganic particles and the PEG have a weight ratio of 3 to 4.

In the disclosure, any range between two values includes the two values. For example, the weight ratio of the inorganic particles and the PEG being 3 to 4 means the weight ratio including 3 and 4.

In one embodiment, the inorganic particles (e.g. spherical particles with a Mohs hardness scale of at least 7) can be silicon oxide, aluminum oxide, silicon carbide, nano diamond, or a combination thereof. In one embodiment, the inorganic particles have a diameter of 200 nm to 5000 nm, or about 300 nm to 1000 nm.

In one embodiment, the PEG has a weight average molecular weight (Mw) of about 100 to 6000. A PEG with an overly high Mw may easily solidify the formulation. A PEG with an overly low Mw may reduce the thickening effect, such that the formulation may drain.

The above PEG can be a PEG with an MW value, or a mixture of different PEGs with different MW values. In one embodiment, the PEG includes a first PEG and a second PEG, wherein the first PEG has a MW of about 100 to 400, the second PEG has a MW of about 600 to 2000, and the first PEG and the second PEG have a weight ratio of 1 to 3. An overly high ratio of the first PEG may reduce the thickening effect, and the formulation may drain. An overly low ratio of the first PEG may easily solidify the formulation.

In one embodiment, about 1 to 10 parts by weight of a filler (based on 100 parts by weight of the inorganic particles) can be added into the above shear thickening formulation, wherein the inorganic particles and the filler have a weight ratio of 10 to 100. The filler may enhance the maximum viscosity or reduce the shear rate of the shear thickening formulation, thereby accelerating the thickening effect. An overly high amount of the filler may easily solidify the formulation or reduce the thickening effect of the formulation. An overly low amount of the filler cannot efficiently enhance the thickening effect. The filler can be nanoclay, nanocellulose, or a combination thereof. In one embodiment, the nanoclay has a diameter of 10 nm to 50 nm and a thickness of 0.1 nm to 2 nm. A nanoclay with an overly large diameter or thickness may reduce the thickening property of the shear thickening formulation. A nanoclay with an overly small diameter or thickness cannot efficiently enhance the thickening effect of the shear thickening formulation. In one embodiment, the nanocellulose has a diameter of 1 nm to 200 nm and a length of 0.01 μm to 100 μm. A nanocellulose with an overly large diameter may easily solidify the shear thickening formulation. A nanocellulose with an overly small diameter cannot efficiently enhance the thickening effect of the shear thickening formulation.

The shear thickening formulation of the disclosure may achieve its maximum viscosity at a shear rate of less than or equal to 20 s^{-1}. In some embodiment, the shear thickening formulation may achieve its maximum viscosity at a shear rate of less than or equal to 10 s^{-1}.

The shear thickening formulation of the disclosure can be applied in various fields if necessary. For example, a composite material utilizing the shear thickening formulation can be utilized in impact resistance, protection, and the like. In one embodiment, a method for preparing the composite material includes: coating the shear thickening formulation of the disclosure onto a matrix (e.g. fiber, fabric, or metal), and pressing the coated matrix at a temperature of 10° C. to 120° C. for 0.05 to 4.5 hours, thereby obtaining a composite with the shear thickening material on a surface of the matrix. Alternately, a method for preparing the composite material includes: impregnating a matrix (e.g. fiber, fabric, or metal) in the shear thickening formulation of the disclosure, stacking the impregnated matrix, and pressing the stack at 60° C. to 100° C. for 0.5 to 4.5 hours, thereby obtaining a com-

TABLE 3

	Silicon oxide (g)	PEG-Mw and amount	Clay (g)	Testing temperature (° C.)	Initial viscosity (cps)	Maximum viscosity (cps)	Shear rate (s^{-1})
Example 4	76	PEG-200 12 g PEG-1000 12 g	0	25	42977	320528	7
Example 6	76	PEG-200 12 g PEG-1000 12 g	1	25	80476	480479	7
Example 7	76	PEG-200 12 g PEG-1000 12 g	2	25	183476	619245	3

As shown in Table 3, the nanoclay in Examples 6 and 7 could enhance the maximum viscosity or reduce the shear rate of the shear thickening formulations, thereby accelerating the thickening effect.

Examples 8 to 10

The physical properties of the shear thickening formulations in Examples 4, 6, and 7 were tested at 75° C., as shown in Table 4.

TABLE 4

	Silicon oxide (g)	PEG-Mw and amount	Clay (g)	Testing temperature (° C.)	Initial viscosity (cps)	Maximum viscosity (cps)	Shear rate (s^{-1})
Example 8	76	PEG-200 12 g PEG-1000 12 g	0	75	30961	91154	9
Example 9	76	PEG-200 12 g PEG-1000 12 g	1	75	34389	148637	8
Example 10	76	PEG-200 12 g PEG-1000 12 g	2	75	71508	279889	4

As shown in Table 4, the mixtures of two PEGs with two Mw values in Examples 8 to 10 made the shear thickening formulations still have fast thickening effect at high temperature. In addition, the nanoclay might further enhance the maximum viscosity or reduce the shear rate of the shear thickening formulations, thereby accelerating the thickening effect.

Example 11

Similar to Example 4, and the difference in Example 11 was 4 g of nanocellulose (Celish KY-100G, diameter of 1 nm to 200 nm, length of 0.01 μm to 100 μm, commercially available from FineChem Ltd.) being further added into the shear thickening formulation. Physical properties of the shear thickening formulations were tested, as tabulated in Table 5.

As shown in comparison between Examples 4 and 11 in Table 5, the nanocellulose had a fast thickening effect, and even reduced the shear rate to accelerate the thickening effect.

[Composite Film Materials 1]

Subsequently, the shear thickening formulations in Examples 1 to 11 were coated on polyamide cellulose and then stacked, and then heated to 80° C. to 90° C. and remained at 80° C. to 90° C. for 0.5 to 3 hours to obtain composite film materials for a non-draining test and a flexible test as described below.

[Non-Draining Test]

The above composite film materials were vertically stood for 3 hour to watch the flowability of the coating resulted from gravity. As a result, no draining phenomenon was observed in these composite film materials.

[Flexible Test]

According to rigid-flexible testing for Taiwan police bullet proof clothing, the samples were tested by a cantilever type rigid-flexible tester. A jointing plate and a sample were simultaneously, slowly, and smoothly slipped forward. When the front end of the sample dropped to a height of a slant line, the slipping of the sample was stopped to record the displacement of the back end of the sample. The smaller displacement means the sample has a higher flexibility (a displacement of less than 28 cm is acceptable). The composite film materials were tested as above, and testing results were tabulated in Table 6.

TABLE 5

	Silicon oxide (g)	PEG-Mw and amount	Nanocellulose (g)	Testing temperature (° C.)	Initial viscosity (cps)	Maximum viscosity (cps)	Shear rate (s^{-1})
Example 4	76	PEG-200 12 g PEG-1000 12 g	0	25	42977	320528	7
Example 11	76	PEG-200 12 g PEG-1000 12 g	4	25	80935	317863	4

What is claimed is:

1. A shear thickening formulation, comprising:

inorganic particles;

polyethylene glycol, wherein the inorganic particles and the polyethylene glycol have a weight ratio of 3:1 to 4:1, the inorganic particles comprise silicon oxide, aluminum oxide, silicon carbide, nanodiamond, or a combination thereof; and

a filler, wherein the inorganic particles and the filler have a weight ratio of 10:1 to 100:1,

wherein the polyethylene glycol comprises a first polyethylene glycol and a second polyethylene glycol, the first polyethylene glycol has a weight average molecular weight of 100 to 400, and the second polyethylene glycol has a weight average molecular weight of 600 to 2000, and

wherein the nanodiamond has a diameter of 200 nm to 5000 nm.

2. The shear thickening formulation as claimed in claim 1, wherein the filler comprises nanoclay, nanocellulose, or a combination thereof, wherein the nanoclay has a diameter of 10 nm to 50 nm and a thickness of 0.1 nm to 2 nm, the nanocellulose has a diameter of 1 nm to 200 nm and a length of 0.01 μm to 100 μm.

3. The shear thickening formulation as claimed in claim 1, wherein the first ethylene glycol and the second ethylene glycol have a weight ratio of 1:1 to 3:1.

4. A composite material, comprising:

a matrix; and

the shear thickening formulation as claimed in claim 1.

5. The composite material as claimed in claim 4, wherein the shear thickening formulation is disposed on a surface of the matrix or in the matrix.

6. The composite material as claimed in claim 4, wherein the filler comprises nanoclay, nanocellulose, or a combination thereof, wherein the nanoclay has a diameter of 10 nm to 50 nm and a thickness of 0.1 nm to 2 nm, the nanocellulose has a diameter of 1 nm to 200 nm and a length of 0.01 μm to 100 μm.

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