[0025] Accordingly, there is still a need for a convenient and economic method of manufacturing a glassy cementitious reagent from globally abundant feedstocks.

[0026] There is also a need to minimize energy consumption and cope with very high and variable melt viscosity without requiring fluxes.

[0027] There is also a need for methods of producing microspheroidal glassy particles and for apparatuses and systems useful for producing such microspheroidal glassy particles.

[0028] The present invention addresses these needs and other needs as it will be apparent from review of the disclosure and description of the features of the invention hereinafter.

SUMMARY

[029a] In one aspect of the present disclosure, there is provided a cementitious reagent, comprising:

particles comprising atoms of Si, Al, Fe, Ca, Mg, Na, and K, in which:

$$\frac{Si}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0.295 \; to \; about \; 0.605$$

$$\frac{Al}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0.190 \; to \; about \; 0.340$$

$$\frac{Fe}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0 \; to \; about \; 0.16$$

$$\frac{Ca + Mg}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0 \; to \; about \; 0.215$$

, and

$$\frac{Na + K}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0.04 \; to \; about \; 0.24,$$

wherein the particles have a spheroidal morphology having a mean roundness (R) > 0.8; and

wherein the particles are at least 80% X-ray amorphous.

[029b] In another aspect of the present disclosure, there is provided a supplementary cementitious material comprising a cementitious reagent, the cementitious reagent comprising non-flyash microspheroidal glassy particles containing Si, Al, Fe, Ca, Mg, Na, and K, in which:

$$\frac{Si}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0.295 \; to \; about \; 0.605$$

$$\frac{Al}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0.190 \; to \; about \; 0.340$$

$$\frac{Fe}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0 \; to \; about \; 0.16$$

$$\frac{Ca + Mg}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0 \; to \; about \; 0.215$$

, and

$$\frac{Na + K}{Si + Al + Fe + (Ca + Mg) + (Na + K)} = 0.04 \; to \; about \; 0.24,$$

wherein the particles have a spheroidal morphology having a mean roundness (R) > 0.8; and

wherein the particles are at least 90% X-ray amorphous.

[029c] In a further aspect of the present disclosure, there is provided a method for producing a cementitious reagent from aluminosilicate materials, comprising the steps of:

providing a solid aluminosilicate material;

milling the solid aluminosilicate material to have a particle size distribution with D[3,2] of less than 20µm;

melting, by in-flight melting, of the aluminosilicate material in a kiln; and

quenching, by in-flight quenching, of the aluminosilicate material to produce solid microspheroidal glassy particles.

[0029] ~~Embodiment~~Examples relate to, among other things, an alternative cement material (ACM), which in some ~~embodiment~~examples comprises a solid microspheroidal glassy particles comprising one or more of the following properties: mean roundness (R) > 0.8 ; and less than about 40% particles having angular morphology (R < 0.7).

[0030] In some ~~embodiment~~examples, the particles comprise a mean roundness (R) of at least 0.9. In ~~embodiment~~examples, less than about 30% particles, or less than about 25% particles, or less than about 20% particles, or less than about 15% particles, or less than about 10% particles have an angular morphology (R < 0.7).

[0031] In some ~~embodiment~~examples, the particles comprise the mean oxide Formula 1: $(CaO,MgO)a•(Na_2O,K_2O)b•(Al_2O_3,Fe_2O_3)c•(SiO_2)d$ [Formula 1]; wherein a is about 0 to about 4, b is about 0.1 to about 1, c is 1, and d is about 1 to about 20.

[0032] In some ~~embodiment~~example<u>s</u>, the particles further comprise one or more of the following properties: (i) a content of 45%-100%, and preferably 90-100%, X-ray amorphous solid; and (ii) molar composition ratios of (Ca,Mg)0-12•(Na,K)0.05-1•(Al, Fe3+)1•Si1-20.

[0033] According to another ~~aspect~~example, some ~~embodiment~~example<u>s</u> relate to a cementitious reagent comprising a mixture of microspheroidal glassy particles as defined herein.

[0034] According to another particular ~~aspect~~example, some ~~embodiment~~example<u>s</u> the ~~invention~~ present disclosure relate to a cementitious reagent comprising a mixture of microspheroidal glassy particles, these particles comprising one or more of the following properties: (i) mean roundness (R) > 0.8; (ii) less than about 20% particles having angular morphology (R < 0.7); (iii) the oxide Formula 1 as defined hereinbefore; (iv) a content of 45%-100%, and preferably 90-100%, X-ray amorphous solid; and (v) a molar composition ratios of $(Ca,Mg)_{0\text{-}12}$•$(Na,K)_{0.05\text{-}1}$•$(Al, Fe^{3+})_{1}$•$Si_{1\text{-}20}$; and (vi) a low

calcium content of about <10wt% CaO, or an intermediate calcium content of about 10 to about 20% wt% CaO, or a high calcium content of >30wt% CaO.

[0035] In some ~~embodiment~~examples, the cementitious reagent is in the form of a non-crystalline solid. In some ~~embodiment~~examples, the cementitious reagent is in the form of a powder. In some ~~embodiment~~examples, the particle size distribution with D[3,2] (i.e., surface area mean, or Sauter Mean Diameter) of about 20µm or less, more preferably 10µm or less, or most preferably 5µm or less. In one ~~embodiment~~example, the mixture of microspheroidal glassy particles of the cementitious reagent comprises the oxide Formula 1 as defined hereinabove. In some ~~embodiment~~examples, the cementitious reagent comprises less than about 10 wt.% CaO. In some ~~embodiment~~examples, the cementitious reagent comprises more than about 30 wt.% CaO. In some ~~embodiment~~examples the cementitious reagent is about 40-100% and preferably about 80% X-ray amorphous, 90% X-ray amorphous, and up to about 100% X-ray amorphous, and in some ~~embodiment~~examples, is 100% non-crystalline.

[0036] According to some ~~embodiment~~examples, a geopolymer binder comprises a cementitious reagent as defined herein. According to another particular ~~aspect~~example, some ~~embodiment~~examples of the present disclosure ~~invention~~ relate to a supplementary cementitious material (SCM) comprising a cementitious reagent as defined herein, for instance a SCM comprising at least 20 wt.% of the cementitious reagent.

[0037] According to another particular ~~aspect~~example, some ~~embodiment~~examples relate to a solid concrete comprising a cementitious reagent as defined herein.

[0038] According to another particular ~~aspect~~example, some ~~embodiment~~examples relate to the use of microspheroidal glassy particles as defined herein, and to the use of a cementitious reagent as defined, to manufacture a geopolymer binder or cement, a hydraulic cement, a supplementary cementitious material (SCM) and/or solid concrete.

[0039] According to another particular ~~aspect~~example some ~~embodiment~~examples relate to a method for producing a cementitious reagent from aluminosilicate materials, comprising the steps of: (i) providing a solid aluminosilicate material; (ii) in-flight melting/quenching said solid aluminosilicate material to melt said material into a liquid and thereafter to quench said liquid to obtain a molten/quenched powder comprising solid microspheroidal glassy particles; thereby obtaining a cementitious reagent with said powder of microspheroidal glassy particles.

[0040] In some ~~embodiment~~examples, the method further comprises step (iii) of grinding said powder of microspheroidal glassy particles into a finer powder. In one ~~embodiment~~example, the powder

comprises particle size distribution with D[3,2] of about 20µm or less, more preferably 10µm or less, or most preferably 5µm or less.

[0041] In some ~~embodiment~~examples, the cementitious reagent obtained by the method comprises one or more of the following properties: is reactive in cementitious systems and/or in geopolymeric systems; delivers workable low yield stress geopolymer cement mixes below 25 Pa when a cement paste has an oxide mole ratio of $H_2O/(Na_2O,K_2O) < 20$]; requires water content in cement paste such that the oxide mole ratio $H_2O/(Na_2O,K_2O) < 20$; and delivers a cement paste with higher workability than an equivalent paste with substantially angular morphology, given the same water content.

[0042] In some ~~embodiment~~examples, the method further comprises the step of adjusting composition of a non-ideal solid aluminosilicate material to a desired content of the elements Ca, Na, K, Al, Fe, and Si. In one ~~embodiment~~example the adjusting comprises blending a non-ideal aluminosilicate material with a composition adjustment material in order to reach desired ratio(s) with respect to one or several of the elements Ca, Na, K, Al, Fe, and Si.

[0043] In some ~~embodiment~~examples, the method further comprises the step of sorting the solid aluminosilicate material to obtain a powder of aluminosilicate particles of a desired size. In some ~~embodiment~~examples, the method further comprises the step of discarding undesirable waste material from said solid aluminosilicate material.

[0044] In some ~~embodiment~~examples, the in-flight melting comprises heating at a temperature above a liquid phase temperature to obtain a liquid. In some ~~embodiment~~examples, the temperature is between about 1000-1600°C, or between about 1300-1550°C.

[0045] In some ~~embodiment~~examples, the method further comprises the step of adding a fluxing material to the solid aluminosilicate material to lower its melting point and/or to induce greater enthalpy, volume, or depolymerization of the liquid. In some ~~embodiment~~examples, the fluxing material is mixed with the solid aluminosilicate material prior to, or during the melting.

[0046] In some ~~embodiment~~examples, the in-flight melting/quenching comprises reducing temperature of the liquid below temperature of glass transition to achieve a solid. In some ~~embodiment~~examples, the in-flight melting/quenching comprises reducing temperature of the liquid below about 500°C, or preferably below about 200°C or lower. In some ~~embodiment~~examples, reducing temperature of the liquid comprises quenching at a rate of about 10^2 Ks^{-1} to about 10^6 Ks^{-1}, preferably at a rate of $>10^{3.5}$ Ks^{-1}. In some ~~embodiment~~examples, quenching comprises a stream of cool

air, steam, or water. In one ~~embodiment~~example, the method further comprises separating quenched solid particles from hot gases in a cyclone separator.

[0047] In some ~~embodiment~~examples, the method for producing a cementitious reagent from aluminosilicate materials further comprises reducing particle size of the powder of solid microspheroidal glassy particles. In some ~~embodiment~~examples reducing particle size comprises crushing and/or pulverizing the powder in a ball mill, a roller mill, a vertical roller mill or the like.

[0048] According to another ~~aspect~~example, some ~~embodiment~~examples relate to an apparatus for producing microspheroidal glassy particles, the apparatus comprising a burner, a melting chamber and a quenching chamber. The melting chamber and the quenching chamber may be completely separate or may be first and second sections of the same chamber, respectively.

[0049] The apparatus may be configured such that solid particles are flown in suspension, melted in suspension, and then quenched in suspension in the apparatus.

[0050] In some ~~embodiment~~examples, the burner provides a flame heating solid particles in suspension to a heating temperature sufficient to substantially melt said solid particles into a liquid. In some ~~embodiment~~examples, the burner comprises a flame that is fueled with a gas that entrains aluminosilicate feedstock particles towards the melt/quench chamber. The gas may comprise an oxidant gas and a combustible fuel. In some ~~embodiment~~examples the burner comprises at least one of a plasma torch, an oxy-fuel burner, an air-fuel burner, a biomass burner, and a solar concentrating furnace.

[0051] In some ~~embodiment~~examples, the quenching chamber of the apparatus comprises a cooling system for providing cool air inside the quenching chamber, the cool air quenching molten particles to solid microspheroidal glassy particles. In some ~~embodiment~~examples, the cooling system comprises a liquid cooling loop positioned around the quenching chamber.

[0052] In some ~~embodiment~~examples, the apparatus further comprises a cyclone separator to collect microspheroidal glassy particles. According to some ~~embodiment~~examples, a method for producing a cementitious reagent from aluminosilicate materials comprises the steps of: (i) providing a solid aluminosilicate material; (ii) in-flight melting/quenching said solid aluminosilicate material to melt said material into a liquid and thereafter to quench said liquid to obtain a molten/quenched powder comprising solid microspheroidal glassy particles; thereby obtaining a cementitious reagent with said powder of microspheroidal glassy particles.

[0053] According to some ~~embodiment~~examples, a method for producing microspheroidal glassy particles comprises the steps of: providing an in-flight melting/quenching apparatus comprising a burner, a melting chamber and a quenching chamber; providing solid particles; flowing said solid particles in suspension in a gas to be burned by said burner; heating said solid particles into said melting chamber to a heating temperature above liquid phase to obtain liquid particles in suspension; and quenching said liquid particles in suspension to a cooling temperature below liquid phase to obtain a powder comprising solid microspheroidal glassy particles.

[0054] In some ~~embodiment~~examples of these methods, the solid particles comprise aluminosilicate materials. In some ~~embodiment~~examples of these methods, the heating temperature is between about 1000-1600°C, or between about 1300-1550°C. In some ~~embodiment~~examples of these methods, the cooling (quench) temperature is below about 500°C, or below about 200°C.

[0055] In some ~~embodiment~~examples of these methods, the quenching comprises providing cool air inside the quenching chamber. In some ~~embodiment~~examples, these methods further comprise collecting the powder with a cyclone separator.

[0056] Additional ~~aspect~~examples ~~of some embodiments~~ of the present disclosure ~~invention~~ relate to the use of an apparatus as defined herein, particularly an apparatus comprising at least one of a plasma torch, an oxy-fuel burner, an air-fuel burner, a biomass burner, and a solar concentrating furnace, for producing microspheroidal glassy particles using in-flight melting/quenching.

[0057] Additional ~~aspect~~examples ~~of some embodiments~~ of the present disclosure ~~invention~~ relate to the use of an apparatus as defined herein, particularly an apparatus comprising at least one of a plasma torch, an oxy-fuel burner, an air-fuel burner, a biomass burner, and a solar concentrating furnace, for producing a cementitious reagent from aluminosilicate materials using in-flight melting/quenching.

[0058] Additional aspects, advantages and features of the present invention will become more apparent upon reading of the following non-restrictive description of preferred embodiments which are exemplary and should not be interpreted as limiting the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0059] A better understanding of the features, advantages and principles of the present disclosure will be obtained by reference to the following detailed description that sets forth illustrative embodiments, and the accompanying drawings of which: