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(71) Applicant *(for all designated States except US)*: **GRAFTECH INTERNATIONAL HOLDINGS INC.** [US/US]; 12900 Snow Road, Attn: Jenn Radike, Parma, OH 44130 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **ELLOITT, Ryan Christopher** [US/US]; 167202 Dartmouth Avenue, Cleveland, Ohio 44111 (US). **SUBRAMANIAN, Prashanth** [IN/US]; 12000 Edgewater Drive #1505, Lakewood, Ohio 44107 (US).

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(54) **Title**: THERMAL INSULATION ASSEMBLY

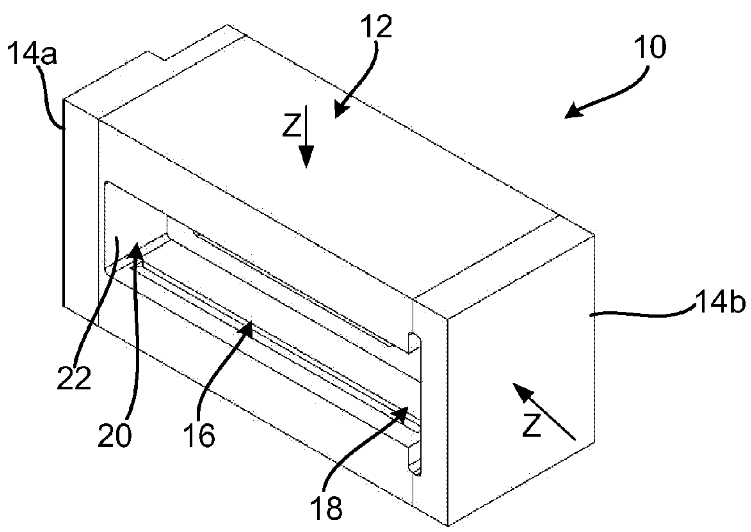

Fig. 1

(57) **Abstract**: A furnace insulation assembly includes a main body having a generally U-shaped cross-section. The main body includes a pair of side walls. A pair of end plates are secured to opposed ends of the main body. The end plates and the main body form an interior chamber. The end plates and side walls are made of a thermal insulation material formed from carbon fibers, said carbon fibers in each end plate and side wall are oriented against-grain direction points inwardly toward the interior chamber.

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DESCRIPTION

THERMAL INSULATION ASSEMBLY

BACKGROUND OF THE INVENTION

[0001] Presently carbon-fiber based materials are being used as insulation materials in many applications. They are particularly well suited for solar applications where high temperatures are required to melt the silicon substrate materials prior to crystallization. Prior art carbon-fiber insulation assemblies for, in particular, string ribbon silicon ovens are made from a single block of carbon-fiber that is cored to form an interior volume.

[0002] There is a need in the art for improved insulation assemblies for silicon furnaces, and in particular insulation assemblies for string ribbon silicon ovens.

SUMMARY OF THE EMBODIMENTS

[0003] According to one aspect of the invention, a furnace insulation assembly includes a main body having a generally U-shaped cross-section. The main body includes a pair of side walls. A pair of end plates are secured to opposed ends of the main body. The end plates and the main body form an interior chamber. The end plates and side walls are made of a thermal insulation material formed from carbon fibers, said carbon fibers in each end plate and side wall are oriented parallel to a with-grain plane and perpendicular to an against-grain direction. The against-grain direction of the end plates and sides walls point inwardly toward the interior chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Fig. 1 is an isometric view of a furnace insulating assembly;

[0005] Fig. 2 is top view the furnace insulating assembly of Fig. 1;

[0006] Fig. 3 is a side view of the furnace insulating assembly of Fig. 1.

DETAILED DESCRIPTION OF THE INVENTION

[0007] Self-supporting, thermal insulation material suited for use in furnace insulation assemblies are described herein below. The thermal insulation material may be formed by, for example, mixing a reinforcement material, such as carbonized fibers, with a liquid binder, such as a sugar solution. The reinforcement material includes carbon fibers, alone or in combination with other carbonized or carbonizable materials. In one embodiment, the fibers include isotropic pitch-based carbon fibers, either alone or mixed with other carbon fibers. In one embodiment, the at least 80% of the carbon fibers are isotropic pitch carbon fibers. In another embodiment, at least 95% of the carbon fibers are isotropic pitch carbon fibers. In still another embodiment, 100% by weight of the carbon fibers are derived from isotropic pitch. In another embodiment, the carbon fibers may be mesophase pitch based carbon fibers. In still another embodiment the carbon fibers may be carbonized rayon fibers. In still another embodiment, the carbon fibers may be carbonized PAN fibers. In still further embodiments, the insulation material may include two or more different types of carbon fibers.

[0008] Insulation materials formed from carbon fibers according to the present method, as large sheets or boards or similar rigid insulation products, have been found to exhibit sufficient strength and insulation properties to make them well suited for high temperature furnaces.

[0009] As used herein, the term “fibers” is intended to encompass all elongate carbon-containing reinforcement materials having a length which is at least twenty times, more preferably, at least 100 times the fiber diameter (often referred to as the aspect ratio). The carbon fibers preferably have an aspect ratio equal to or greater than 20:1, more preferably, greater than 100:1, a length of from about 2-30 mm, and a diameter of about 5-15 microns.

[00010] The fibers are combined with a liquid binder which holds the fibers together during the subsequent processing stages. Preferred binders comprise an aqueous solution of a soluble sugar, such as a monosaccharide or disaccharide. Exemplary sugars include sucrose, fructose, dextrose, maltose, mannose glucose, galactose, UDP-galactose, and xylose, their soluble polysaccaride equivalents, and combinations thereof.

[00011] The binder solution and fibers are mixed together in a ratio of about 10-40 parts by weight of binder solution to about 60-40 parts of fiber. In terms of sugar (*i.e.*, not including the water) a preferred ratio is from 20-80% by weight sugar: 80-20% by weight fibers, most preferably, about 40% by weight sugar: 60% by weight fibers. For sucrose, which has a carbon yield of about 35%, this ratio results in a product (after baking described herein below) having about 14% of carbonized sugar and 86% fibers by weight. Preferably, the carbonized sugar content of the product is between about 10% and about 20% by weight. If the carbonized sugar is too low, the integrity of the final product may be compromised. As the concentration of carbonized sugar increases, the density tends to increase, increasing the thermal conductivity of the material and rendering it less well suited for thermal insulation applications.

[00012] The fibers of the insulation material used in the furnace insulation assembly described herein below are not randomly aligned, but are generally randomly arranged parallel to a with-grain plane (i.e. perpendicular to the against-grain direction) in each insulation assembly piece. At least 60 percent, more advantageously 80 percent, and even more advantageously 90 percent of the fibers are substantially parallel to the with-grain plane. This fiber alignment may be achieved by, for example pouring a mixture of fibers and binder into a form or mold fitted with a filter at one end and removing excess binder by gravity or a vacuum source. In this manner, the fibers build up on the filter and when the desired thickness is achieved, the fibers and remaining binder are removed as a pre-form.

[00013] For higher density products, light pressure may be applied to the pre-form, either during filtration or during a subsequent heating step, although excessive pressure can compromise the insulative properties of the finished product. Preferably, the pressure, if applied, does not result in a final density of the insulation product of more than about 0.5 g/cm^3.

[00014] The pre-form may be heated to a temperature of about 200°C to 300°C to drive off water from the binder solution. It is also contemplated that the filtering step may be eliminated and that the mixture simply be heated, first to drive off excess water and later in the heating process, to convert the remaining sugar to a polymeric form.

[00015] The pre-form is then carbonized at a final temperature of about 900°C to about 2000°C in an inert (non-oxidizing) atmosphere, such as argon to remove all (or substantially all) oxygen and hydrogen and produce a carbonized article in the desired shape. The carbonization temperature is selected according to the end use of the casting and is generally above the highest temperature to which the casting is to be subjected in use. This reduces the chance for out-gassing during use.

[00016] The resulting carbonized article comprises primarily carbon (*i.e.*, at least 95% carbon, more preferably, at least 98% carbon, most preferably, greater than 99.5% carbon) and has a density of typically less than about 1 g/cm^3, preferably less than 0.5 g/cm^3, more preferably less than 0.3 g/cm^3, which is suitable for thermal insulation. The article is sectioned or machined to an appropriate size as will be described hereinbelow.

[00017] The insulation articles produced by the above method are well suited to use at temperatures of 1500-2000°C, or higher. The insulation material has a low density of 0.1 to 0.40 g/cm^3, more preferably, from 0.15-0.25 g/cm^3, and a thermal conductivity in the against-grain direction (i.e. perpendicular to the plane of orientation of the fibers) of less than about 0.4 W/m°K, more preferably less than about 0.3 W/m°K and even more preferably less than about 0.2 W/m°K. In this or other embodiments, the thermal conductivity may be from between about 0.15 to about 0.2 W/m°K. (All thermal conductivities are measured in air at 25°C, unless otherwise noted). The thermal conductivity in the with-grain direction (i.e. parallel to the plane of orientation of the fibers) is relatively higher than the against-grain direction. In one embodiment the ratio of against-grain thermal conductivity to with-grain thermal conductivity is less that about .6. In other embodiments, the ratio of against-grain thermal conductivity to with-grain thermal conductivity is less than about .5. In other embodiments, the ratio of against-grain thermal conductivity to with-grain thermal conductivity is less than about .42. In other embodiments the ratio of against-grain thermal conductivity to with-grain thermal conductivity is from between about .2 and about .8. In still other embodiments the ratio of against-grain thermal conductivity to with-grain thermal conductivity is from between about .3 and about .5. In this or other embodiments, the with-grain thermal conductivity may be greater than about 0.3 W/m°K. In other embodiments the with-grain thermal conductivity may be from between about 0.3 to about 1 W/m°K. In other embodiments, the with-grain thermal conductivity may be from between about 0.3 to about 0.5 W/m°K. Further, high strength levels, greater than 150 psi, are readily obtained in such low density products.

[00018] With reference now to Figs. 1-3, a furnace insulation assembly according to the present invention is shown and generally indicated by the numeral 10. Insulation assembly 10 includes three separate parts including a main body 12 and a pair of end plates 14a and 14b. As can be seen, main body 12 is in the form of an elongated rectangle having a longitudinal length approximately two times the height and width thereof. It should be appreciated however that the body 12 length shown and described is merely exemplary and may be shorter or longer depending on the application. The body portion 12 includes generally U-shaped cross-section that forms a chamber 16. As can be seen from the figures, chamber 16 may include various surface features, notches or channels as may be required for the heating and substrate elements (not shown) that are received therein.

[00019] A first end 18 of the main body 12 is open and a second end 20 includes a wall section 22. As can be seen, the with-grain plane of main body 12 runs along the length and height thereof. This configuration is advantageous because the thermal conductivity described hereinabove of the insulating material is relatively lower in the against-grain direction (labeled the Z direction in the figures). Therefore, the longitudinal side walls 24 are oriented to provide maximum insulative effect. Put another way, the side walls 24 include two opposed major surfaces and the Z direction is oriented perpendicular to the major surfaces.

[00020] End plates 14a and 14b are secured to opposed ends of main body 12 respectively. End plates 14 may be secured to main body 12 via any appropriate means including, but not limited to, adhesives, mechanical fasteners or combinations thereof. As can be seen, the with-grain plane of end plates 14 runs along the width and height of the insulation assembly. As discussed above, this configuration is advantageous because the end plates 14 are oriented to provide maximum insulative effect. In this manner, the side walls 24 and end walls 14 are oriented so that the against-grain direction of each part points inwardly toward interior chamber 16. Thus, the maximum insulative property of the insulation material is obtained.

[00021] The above described insulation assembly is particularly applicable for use in a string ribbon puller for the solar industry. However, the assembly may be used in other solar and silicon based applications requiring improved energy efficiency. It should further be appreciated that, though the above described embodiment disclosed a three-piece insulation assembly, more than three pieces might be employed, for a separate piece might be used for each exterior facing wall and arranged such that the against-grain direction for each wall points inwardly toward the chamber.

[00022] The invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS

<u>What is claimed is:</u>

1. A furnace insulation assembly comprising:

a main body having a generally U-shaped cross-section, said main body including a pair of opposed and spaced side walls;

a pair of end plates secured to opposed ends of the main body, said end plates and said main body forming an interior chamber; and

wherein said end plates and said side walls are made of a thermal insulation material formed from carbon fibers, said carbon fibers in each said end plate and said side walls being substantially oriented parallel to a with-grain plane and perpendicular to an against-grain direction, said against-grain direction of said end plates and said sides wall pointing inwardly toward said interior chamber.

2. The furnace insulation assembly of claim 1 wherein at least 60 percent of said fibers are parallel to said with-grain plane.

3. The furnace insulation assembly of claim 1 wherein at least 80 percent of said fibers are parallel to said with-grain plane.

4. The furnace insulation assembly of claim 1 wherein at least 90 percent of said fibers are parallel to said with-grain plane.

5. The furnace insulation assembly of claim 1 wherein said thermal insulation material having a density of from about 0.1 to about 0.4 g/cm^3.

6. The furnace insulation assembly of claim 1, wherein the thermal insulation material has an against-grain thermal conductivity of less than about 0.4 W/m°.K.

7. The furnace insulation assembly of claim 1, wherein the thermal insulation material has an against-grain thermal conductivity of less than about 0.2 W/m°.K.

8. The furnace insulation assembly of claim 1 wherein at least some of said carbon fibers are derived from isotropic pitch.

9. The furnace insulation assembly of claim 1 wherein at least some of said carbon fibers are derived from rayon.

10. The furnace insulation assembly of claim 1 wherein at least some of said carbon fibers are derived from PAN.

11. The furnace insulation assembly of claim 1 wherein the ratio of against-grain thermal conductivity to with-grain thermal conductivity is less that about 0.6.

12. The furnace insulation assembly of claim 1 wherein the ratio of against-grain thermal conductivity to with-grain thermal conductivity is less than about 0.5.

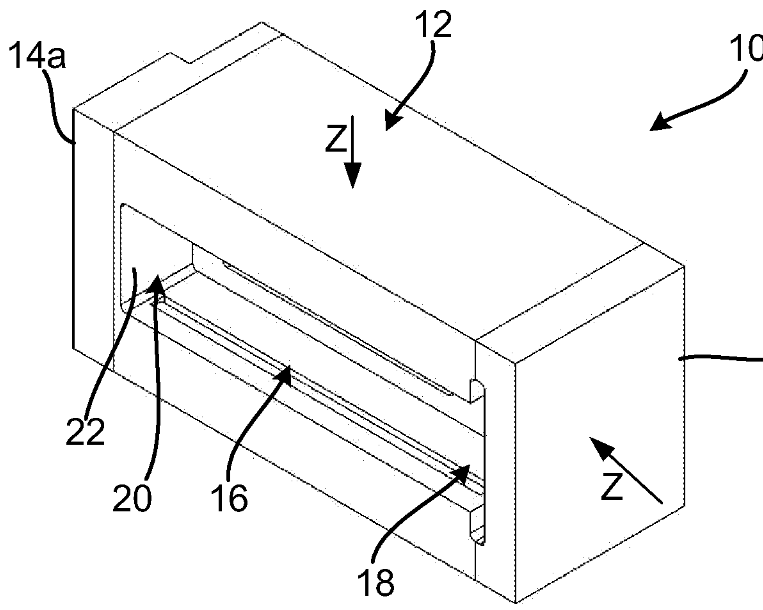

Fig. 1

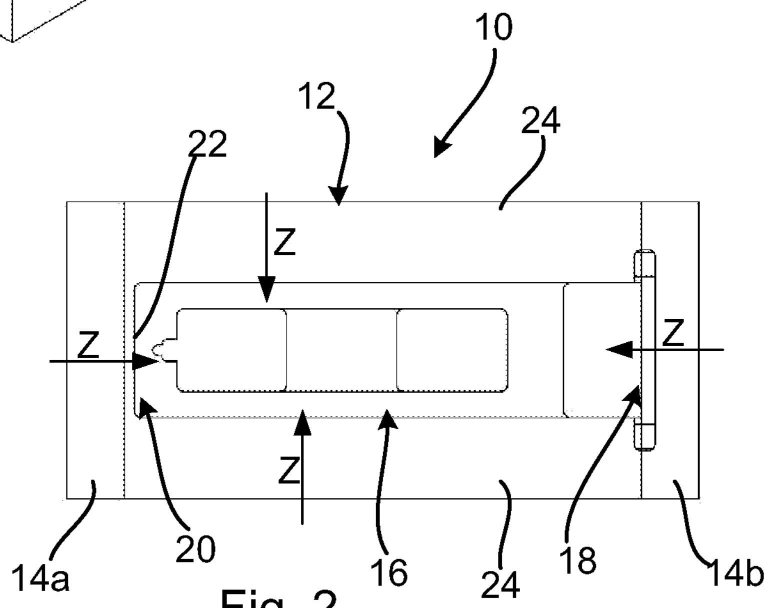

Fig. 2

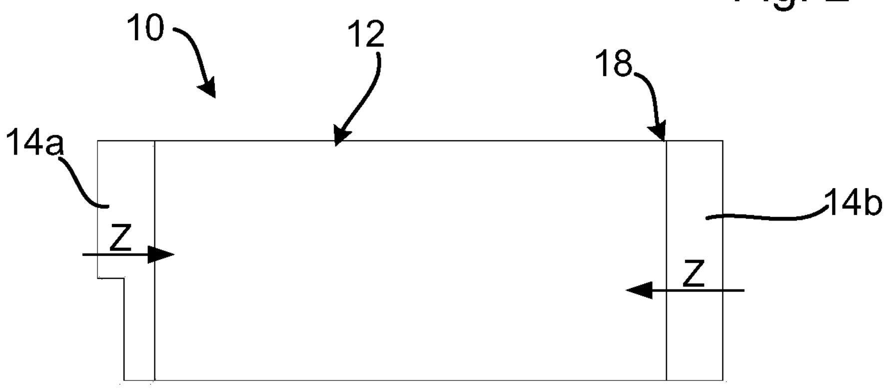

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 12/43715

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F23M 5/00; F27D 1/00 (2012.01)
USPC - 110/336
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC - 110/336

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 110/336 (text search - see search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (USFT, PGPUB, EPAB, JPAB); Google Scholar/Patent. Search terms: "PAN", carbon, conductivity, core, cored, direction, end, fiber, furnace, grain, insulation, isotropic, open, oriented, oven, parallel, perpendicular, pitch, plate, rayon, ribbon, silicon, sting, thermal, top, u-shaped, wall

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,394,766 A (Karagoz) 19 July 1983 (19.07.1983), especially col. 2 ln 35-45; col. 6 ln 8, 22	1-12
Y	US 7,150,837 B2 (Chiu et al.) 19 December 2006 (19.12.2006), especially col 2 ln 16-18; col 5 ln 60-63; col 6 ln 10-20; col 7 ln 35-45; col 8 ln 45-50. Table 1, 2	1-12
Y	US 5,705,106 A (Kolesnikov et al.) 06 January 1998 (06.01.1998), especially col. 1 ln 58-62	1-12

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 August 2012 (15.08.2012)	06 SEP 2012

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774