Abstract:
Disclosed herein are abrasive filaments with improved stiffness and industrial brushes comprising the same, wherein the abrasive filaments are formed of polyamide compositions comprising, (a) at least one polyamide; (b) about 0.1-1 wt% of at least one linear chain extending compound that has a molecular weight of 1000 Daltons or lower; (c) about 0.1-1 wt% of at least one anti-oxidant; and (d) about 10-40 wt% of abrasive particles, with the total wt% of all components in the composition totaling to 100 wt%.
ABRASIVE FILAMENTS WITH IMPROVED STIFFNESS AND INDUSTRIAL BRUSHES
COMPRISING THE SAME AND USES THEREOF

FIELD OF DISCLOSURE

The present disclosure is related to abrasive filaments with improved stiffness, industrial brushes comprising the abrasive filaments, and the uses of the industrial brushes.

BACKGROUND

Abrasive filaments made from polyamides filled with abrasive particles were developed in the late 1950's as a man made alternative to natural abrasive filaments. At about that time an extrusion process was developed for dispersing abrasive particles uniformly in a polyamide matrix in the form of a filament (U.S. Patent Nos. 3,522,342 and 3,947,169). Some of the advantages of polyamide abrasive filaments are their safety, cleanliness, cutting speed, low cost, superior radius and finish control, adaptability, and ease to design.

A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. In crystal silicon based solar cells, silicon wafers are made by wire-sawing block-cast silicon ingots into very thin (180 to 350 μm) slices or wafers. A typical process of manufacturing silicon wafers often includes pulling a crystal silicon ingot; grinding the ingot; sawing off the ingot ends; and sawing up the ingot into wafers. In certain processes, the ingot is further polished using industrial brushes after the ingot ends are sawn off. Currently, polyamide based industrial brushes are often used in polishing the ingot. However, it is found that the polyamide based industrial brushes, due to the relative softness of the filaments, often causes end-rounding at the two longitudinal ends of the ingot and therefore reduces the production rate of silicon wafers. Thus, there is still a need to develop polyamide based abrasive filaments with improved stiffness and therefore increase the production rate of silicon wafers.
Various chain extending additives have been used in the prior art to improve the relative viscosity (RV) and other properties of polyamides. For example, U.S. Patent No. 7,005,097 discloses a polyamide composition in forming medical devices such as catheters or balloons. It is also disclosed that the addition of the bis-lactam compound, bis-oxazoline compound, or bis-oxazine compound based chain extending additive in the polyamide composition improves the RV of the composition and the wall strength of the medical device made therefrom. Further, PCT Patent Application No. WO201 0033671 discloses the use of polycarbodiimide in polyamide based brush filaments to improve the hydrolysis resistance thereof. Yet, none of these references teaches that the addition of linear chain extending compounds may improve the flexural modulus or stiffness of polyamides.

**SUMMARY**

One of the purpose of the present disclosure is to provide an abrasive filament with improved stiffness, wherein the abrasive filament is formed of a melt blended polyamide composition, and wherein the polyamide composition comprises: (a) at least one polyamide; (b) 0.1-1 wt% of at least one linear chain extending compound having a molecular weight of 1000 Daltons or lower; (c) 0.1-1 wt% of at least one antioxidant; and (d) 10-40 wt% of abrasive particles, with the total wt% of all components in the composition totaling to 100 wt%.

In one embodiment of the abrasive filament, the at least one linear chain extending compound is selected from the group consisting of bis-lactam compounds, bis-oxazoline compounds, bis-oxazine compounds, and combinations of two or more thereof. In such embodiments, the bis-lactam compounds are selected from the group consisting of N,N'-isophthaloyl bis-caprolactam; N,N'-adipoyl bis-caprolactam; N,N'-terephthaloyl bis-caprolactam; N,N'-isophthaloyl bis-butyrrolactam; carbonyl bis-caprolactam; and combinations of two or more thereof, and the bis-oxazoline compounds and bis-oxazine compounds are selected from the group consisting of 2,2'-bis(2-oxazoline); 2,2'-bis(4-methyl-2-oxazoline); 2,2'-bis(4-phenyl-2-oxazoline); 2,2'-bis(4-hexyloxazoline); 2,2'-p-phenylene bis(2-oxazoline); 2,2'-m-phenylene bis(2-oxazoline); 2,2'-tetramethylene bis(4,4'-
dimethyl-2-oxazoline); the corresponding oxazines; and combinations or two or more thereof. Or, the at least one linear chain extending compound is carbonyl bis-caprolactam.

In a further embodiment of the abrasive filament, the at least one linear chain extending compound is present in the polyamide composition at a level of 0.2-0.7 wt%, based on the total weight of the polyamide composition.

In a yet further embodiment of the abrasive filament, the at least one antioxidant is selected from sterically hindered phenols. Or, the at least one antioxidant is selected from the group consisting of pentaerythritol tetrakis (3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate; 3,3',3',5,5',5'-hexa-tert-butyl-a,a',a''-(mesitylene-2,4,6-triy)tri-p-cresol; N,N'-hexane-1,6-diylbis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide)); octadecyl-3-(3,5-di-tert.butyl-4-hydroxyphenyl)-propionate; and combinations of two or more thereof. Or, the at least one antioxidant is N,N'-hexane-1,6-diylbis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide)).

In a yet further embodiment of the abrasive filament, the at least one antioxidant is present in the polyamide composition at a level of 0.2-0.7 wt%, based on the total weight of the polyamide composition.

In a yet further embodiment of the abrasive filament, the abrasive particles are selected from the group consisting of organic abrasive particles, inorganic abrasive particles, and combinations thereof. Or, the abrasive particles are selected from the group consisting of particles based on aluminum oxides, alpha alumina, silicon carbides, titanium diborides, alumina zirconia, diamond, boron carbide, ceria, aluminum silicates, cubic boron nitride, garnet, silica, pumice, sand, emery, mica, corundum, quartz, and combinations of two or more thereof.

In a yet further embodiment of the abrasive filament, the at least one polyamide is selected from aliphatic polyamides.

In a yet further embodiment of the abrasive filament, the at least one polyamide is selected from the group consisting of polyamide 4,6; polyamide 6; polyamide 6,6; polyamide 6,1 0; polyamide 6,1 2; polyamide 6,1 3; polyamide 6,1 4; polyamide 6,1 5; polyamide 6,1 6; polyamide 9,1 0; polyamide 9,1 2; polyamide 9,1 3; polyamide 9,1 4;
polyamide 9,15; polyamide 9,36; polyamide 10,10; polyamide 10,12; polyamide 10,13; polyamide 10,14; polyamide 11; polyamide 12; polyamide 12,10; polyamide 12,12; polyamide 12,13; polyamide 12,14; and combinations of two or more thereof, or the at least one aliphatic polyamide is selected from polyamide 6,10; polyamide 6,12; and combinations thereof.

In a yet further embodiment of the abrasive filament, the at least one polyamide has a relative viscosity of 2.3-5, or 2.3-4, or 2.3-3.5.

In a yet further embodiment of the abrasive filament, the at least one polyamide is present in the polyamide composition at a level of 60-90 wt%, or 60-80 wt%, or 60-75 wt%, based on the total weight of the polyamide composition.

In a yet further embodiment of the abrasive filament, the abrasive filament is prepared by a continuous melt spinning process, and wherein the process comprises: (i) blending the at least one polyamide, the at least one linear chain extender compound, and the at least one antioxidant into a mixture; (ii) passing the mixture through an extruder while the abrasive particles are added into the extruder through one or more side feeders; and (iii) melt spinning the composition that comes out of the extruder into filaments.

In a yet further embodiment of the abrasive filament, the abrasive filament is prepared by a two-step melt spinning process, and wherein the process comprises: (i) melt compounding the at least one polyamide, the at least one linear chain extender compound, and the at least one antioxidant into resin pellets; (ii) passing the resin pellets through an extruder while the abrasive particles are added into the extruder through one or more side feeders; and (iii) melt spinning the composition that comes out of the extruder into filaments.

A further purpose of the present disclosure is to provide an industrial brush comprising a plurality of the abrasive filaments described above.

A yet further purpose of the present disclosure is to provide the use of the industrial brush described above in grinding and/or polishing silicon ingots, stone, or metal parts.

A yet further purpose of the present disclosure is to provide the use of the industrial brush in grinding and/or polishing silicon ingots.
In accordance with the present disclosure, when a range is given with two particular end points, it is understood that the range includes any value that is within the two particular end points and any value that is equal to or about equal to any of the two end points.

DETAILED DESCRIPTION

Disclosed herein are abrasive filaments formed of a melt blended polyamide composition, wherein the polyamide composition comprises: (a) at least one polyamide; (b) about 0.1 - 1 wt% of at least one linear chain extending compound having a molecular weight of about 1000 Daltons or lower; (c) about 0.1 - 1 wt% of at least one antioxidant, and (d) about 10-40 wt% of abrasive particles, with the total wt% of all components in the composition totaling to 100 wt%.

Polyamides are condensation copolymers formed by reacting equal parts of one or more diamines and one or more dicarboxylic acids, so that amides are formed at both ends of each monomer in a process analogous to polypeptide biopolymers. It is understood that the polyamides used herein also include co-polyamides, which are copolymers formed by polymerizing two or more polyamide monomers or by reacting equal parts of two or more diamines and two or more dicarboxylic acids. In addition, the at least one polyamide comprised in the melt blended polyamide composition also may be a blend of two or more polyamides. Moreover, the polyamides used herein may have a relative viscosity (RV) of about 2.3-5, or about 2.3-4, or about 2.3-3.5.

Preferably, the polyamides used herein are aliphatic polyamides. The term "aliphatic polyamide" is used to refer to a polyamide containing no aromatic ring in its molecular chain and is a condensation product of an aminocarboxylic acid, a lactam, or a diamine and a dicarboxylic acid.

The aminocarboxylic acids used here may be aminocarboxylic acids having 6 to 12 carbon atoms, which include, but are not limited to, 6-aminocapronic acid, 7-
aminoheptanoic acid, 9-aminononanoic acid, 11-aminoundecanoic acid, 12-
aminododecanoic acid, and the like.

The lactam used here may be lactams having 4 to 12 carbon atoms, which include, but are
not limited to, a-pyrrolidone, ε-caprolactam, ω-laurolactam, ε-enantholactam, and the like.

The diamines used here may be aliphatic or alicyclic diamines, including but not
limited to, tetramethylenediamine; hexamethylenediamine; 2 methylpentamethylenediamine;
nonamethylenediamine; undecamethylenediamine; dodeca-methylenediamine; 2,2,4-
trimethylhexamethylenediamine; 2,4,4-trimethylhexamethylenediamine; 5-
methyleneamamethylene-diamine; 1,3-bis(aminomethyl)cyclohexane; 1,4-
bis(aminomethyl)cyclohexane; 1-amino-3 aminomethyl-3,5,5-trimethylcyclohexane; bis(4-
aminocyclohexyl)methane; bis(3-methyl-4-aminocyclohexyl)methane; 2,2-bis(4-
aminocyclohexyl)propane; bis(aminoethyl)piperazine; aminoethylpiperazine; bis(p-
aminocyclohexyl)methane; 2-methyloctamethylenediamine; trimethylhexamethylenediamine;
trimethylhexamethylenediamine; 1,8-diaminooctane; 1,9-diaminononane; 1,10-
diaminodecane; 1,12-diaminododecane; m-xylylenediamine; and the like.

The dicarboxylic acids used herein may be aliphatic or alicyclic dicarboxylic acids,
including but not limited to, adipic acid; glutaric acid; pimelic acid; suberic acid; azelaic acid;
sebacic acid; dodecanedioic acid; 1,4-cyclohexanedicarboxylic acid; and the like.

Examples of preferred aliphatic polyamides include, but are not limited to, polyamide
4,6; polyamide 6; polyamide 6,6; polyamide 6,1 0 ; polyamide 6,1 2 ; polyamide 6,1 3 ;
polyamide 6,14; polyamide 6,1 5 ; polyamide 6,1 6 ; polyamide 9,1 0 ; polyamide 9,1 2 ;
polyamide 9,1 3 ; polyamide 9,1 4 ; polyamide 9,1 5 ; polyamide 9,1 6 ; polyamide 9,3 6 ; polyamide 10,1 0 ;
polyamide 10,1 2 ; polyamide 10,1 3 ; polyamide 10,1 4 ; polyamide 11; polyamide 12;
polyamide 12,1 0 ; polyamide 12,1 2 ; polyamide 12,1 3 ; polyamide 12,14; and combinations
of two or more thereof. In one embodiment, the at least one aliphatic polyamide comprised
in the polyamide resin is selected from polyamide 6,1 0 ; polyamide 6,1 2 ; and
combinations thereof.

In accordance to the present disclosure, the at least one polyamide may be present
in the composition at a level of about 60-90 wt%, or about 60-80 wt%, or about 60-75 wt%.
The linear chain extending compounds used herein are low molecular weight (<1000 Daltons) compounds that have bi-functional end groups. Such linear chain extending compounds are reactive with the terminal groups of polyamides but are essentially non-crosslinking. The at least one linear chain extending compound used herein may be selected from bis-lactam compounds, bis-oxazoline compounds, bis-oxazine compounds, and combinations of two or more thereof.

The bis-lactam compounds used herein may be represented by the following general formula (I):

(I)

\[(\text{H}_2\text{C})_n\text{N} - \text{R} - \text{N}(\text{CH}_2)_m\]

in which one or more of the methylene hydrogen atoms may alternatively be substituted by an alkyl or aryl radical; R represents a divalent organic radical; and n is an integer of 2-15.

In one embodiment, the R group in formula (I) may have a general formula (II):

(II)

\[\text{C} - \text{A} - \text{C}\]

wherein A is a divalent organic group. Suitably A is a hydrocarbon group of about 20 carbons or less or a (poly)ether group. Exemplary A groups include, without limitation, alkylene groups (e.g., methylene; ethylene; 1,2 propylene; 1,3 propylene; or hexamethylene); arylene groups (e.g., phenylene; methylphenylene; naphthylene; 4,4'-biphenylene; a bisphenol A residue; or a bisphenol S residue); alkarylene groups (e.g., ethylenephenylene); and ether interrupted hydrocarbon groups (e.g., ethyleneoxyethylene; polyethylenoxyethylene; polyethylenoxypropylene; or (polypropylenoxy)ethylene).

In a further embodiment, the R group in formula (I) may have a general formula (III):

(III)

\[\text{C} - \text{B} - \text{C}\]
wherein B is -NH-A-NH, with A being as previously defined.

In a yet further embodiment, the R group in formula (I) may simply be a carbonyl group with a general formula (IV):

\[
\begin{align*}
\text{(IV)} \\
\end{align*}
\]

Compounds employing such carbonyl linkages are designated as "carbonyl bis-lactams". Suitable carbonyl bis-lactam compounds may have the general formula (V):

\[
\begin{align*}
\text{(V)} \\
\end{align*}
\]

in which n is an integer of 3-15, or preferably an integer of 5-12.

Bis-lactam compounds useful herein include those disclosed in U.S. Patent No. 6,228,980; PCT Patent Application No. WO 96/34909; and European Patent No. EP 0288253. Specific examples include, without limitation, N,N'-isophthaloyl bis-caprolactam; N,N'-adipoyl bis-caprolactam; N,N'-terephthaloyl bis-laurolactam; N,N'-isophthaloyl bis-butyrolactam; carbonyl bis-caprolactam; and combinations of two or more thereof.

The bis-oxazoline and bis-oxazine compounds used herein are both described by the formula (VI):

\[
\begin{align*}
\text{(VI)} \\
\end{align*}
\]

where X is a divalent hydrocarbon group and the ring is a 5-membered ring for the bis-oxazoline or a 6-membered ring for the bis-oxazine, respectively; n=0 or 1; and D is a divalent organic group. And X may be an ethylene group, a substituted ethylene group, a trimethylene, or a substituted trimethylene group. As substituent, for instance an alkyl group with 1 to 10 carbon atoms, an aryl group, a cycloalkyl group, or an aralkyl group may be present. Exemplary alkyl groups include, without limitation, methyl, ethyl, hexyl, alkylhexyl,
and nonyl groups; exemplary aryl groups include, without limitation, phenyl, naphthyl, and
diphenyl groups; and exemplary cycloalkyl groups include, without limitation, cyclohexyl. D
may be suitably a hydrocarbon group, e.g., an alkylene group, an arylene group, a
cycloalkylene group, or an aralkylene group.

Examples of bis-oxazolines and bis-oxazines include, without limitation, 2,2'-bis(2-
oxazoline); 2,2'-bis(4-methyl-2-oxazoline); 2,2'-bis(4-phenyl-2-oxazoline); 2,2'-bis(4-
hexyloxazoline); 2,2'-p-phenylene bis(2-oxazoline); 2,2'-p-phenylene bis(2-oxazoline); 2,2'-
tetramethylene bis(4,4'-dimethyl-2-oxazoline); and the corresponding oxazines. Preference
is given to 2,2'-bis(2-oxazoline); 2,2'-p-phenylene bis(2-oxazoline) (1,4-PBO); 2,2'-m-
phenylene bis(2-oxazoline) (1,3-PBO); and the corresponding oxazines.

The linear chain extending compounds used herein also may be obtained
commercially from various vendors, which include, without limitation, carbonyl
biscaprolactam (CBC) available from DSM (the Netherlands) under trade name ALLINCO™;
1,4-phenylene bisoxazoline (1,4-PBO) available from DSM under trade name ALLINCO™;
and 2,2'-m-phenylene bis(2-oxazoline) (1,3-PBO) available from Takeda Chemical
Industries (Japan) or from Mikuni Pharmaceutical Industrial Co., LTD. (Japan).

In accordance to the present disclosure, the at least one linear chain extending
compound may be present in the polyamide composition at a level of about 0.1-1 wt% or
about 0.2-0.7 wt%.

The process of incorporating the linear chain extending compounds can be carried
out in a simple manner using the usual extruder melt-mixing techniques and equipment, for
example by blending the terminally reactive polymer and the chain extender in a solid state.
In some cases a small quantity (preferably no more than about 0.2%) of an oily processing
aid may be added to the dry mix to improve the uniformity of distribution of the chain
extender in the dry mix. The dry mix so obtained, is then melted in a conventional melt-
mixing apparatus, for example a single- or double-screw extruder. Alternatively the
polymer composition may be prepared in another type of melt mixer and then subsequently
provided to the extruder directly from the initial melt mixer. The different components can
also be fed to the extruder or other mixing apparatus separately. Chain extenders, in any
form, can be fed into an extruder separately from the polymer resin by continuous feeding equipments.

Any suitable type of antioxidants may be used herein. Preferably, the antioxidants used herein are sterically hindered phenols. For examples, the antioxidants used herein may be selected from pentaerythritol tetrakis (3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate (CAS No. 6683-19-8, available from BASF (Germany) under the trade name Irganox™ 1010); 3,3',3',5,5',5'-hexa-tert-butyl-a,a',a'-(mesitylene-2,4,6-triyl)trip-cresol (CAS No. 1709-70-2, available from BASF under the trade name Irganox™ 1330); N,N'-hexane-1,6-diylbis(3-(3,5-di-tert-butyl-4-hydroxyphenylpropionamide)) (CAS No. 23128-74-7, available from BASF under the trade name Irganox™ 1098); octadecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)-propionate (CAS No. 2082-79-3, available from BASF under the trade name Irganox™ 1076); and combinations of two or more thereof.

In accordance to the present disclosure, the at least one antioxidant may be present in the polyamide composition at a level of about 0.1-1 wt% or about 0.2-0.7 wt%.

The abrasive particles used herein may be organic or inorganic and may have a particle size of about 0.1-1500 μm, or about 1-1000 μm, or about 50-500 μm. Exemplary inorganic abrasive particles that are useful herein include, without limitation, aluminum oxides (e.g., fused aluminum oxides or heat treated aluminum oxides), alpha alumina, silicon carbides, titanium diborides, alumina zirconia, diamond, boron carbide, ceria, aluminum silicates, cubic boron nitride, garnet, silica, pumice, sand, emery, mica, corundum, quartz, and combinations of two or more thereof. Exemplary fused aluminum oxide particles include those available commercially from Exolon ESK Company (U.S.A.) or Washington Mills Electro Minerals Corp. (U.S.A.). Suitable ceramic aluminum oxide particles include those described in U.S. Patent Nos. 4,314,827; 4,623,364; 4,744,802; 4,770,671; 4,881,951; 4,964,883; 5,011,508; and 5,164,348. Suitable alpha alumina-based ceramic particles that comprise alpha alumina and rare earth oxide include those commercially available from 3M Company (U.S.A.) under the trade name CUBITRON™ 321. Also suitable herein are shaped abrasive particles, such as those disclosed in U.S. Patent Nos. 5,009,676; 5,185,012; 5,244,477; and 5,372,620. Other
examples of particles useful herein include solid glass spheres, hollow glass spheres, calcium carbonate, polymeric bubbles, silicates, aluminum trihydrate, and mullite.

As used herein, the term abrasive particle also encompasses single abrasive particles which are bonded together to form an abrasive agglomerate. Abrasive agglomerates are further described in U.S. Patent Nos. 4,311,489; 4,652,275; and 4,799,939. The abrasive particles used herein may also contain a surface coating. Surface coatings are known to improve the adhesion between the abrasive particles and the binder. Suitable surface coatings are described in, e.g., U.S. Patent Nos. 5,011,508; 1,910,444; 3,041,156; 5,009,675; 4,997,461; 5,213,591; and 5,042,991. In some instances, the addition of the coating improves the abrading and/or processing characteristics of the abrasive particles.

Organic abrasive particles useful herein include those formed from a thermoplastic polymer and/or a thermosetting polymer. Organic abrasive particles useful herein may be individual particles or agglomerates of individual particles. The agglomerates may comprise a plurality of the organic abrasive particles bonded together by a binder to form a shaped mass.

The organic abrasive particles used herein may have any precise shape or may be irregularly or randomly shaped. Examples of such three dimensional shapes include, without limitation, pyramids, cylinders, cones, spheres, blocks, cubes, polygons, and the like. Alternatively, the organic abrasive particles may be relatively flat and have a cross sectional shape such as a diamond, cross, circle, triangle, rectangle, square, oval, octagon, pentagon, hexagon, polygon and the like.

The surface of the organic abrasive particles (a portion of their surface, or the entire surface) may be treated with coupling agents to enhance adhesion to and/or dispersibility in the molten thermoplastic matrix. The organic abrasive particles are not required to be uniformly dispersed in the hardened composition, but a uniform dispersion may provide more consistent abrasion characteristics.

The organic abrasive particles may be formed from a thermoplastic material such as polycarbonate, polyetherimide, polyester, polyvinyl chloride, methacrylate,
methylmethacrylate, polyethylene, polysulfone, polystyrene, acrylonitrile-butadiene-styrene
block copolymer, polypropylene, acetal polymers, polyurethanes, polyamide, and
combinations thereof. In general, preferred thermoplastic material used herein as the
organic abrasive particles are those having a high melting temperature, e.g. greater than
200°C or 300°C; or good heat resistance properties. Moreover, the organic abrasive
particles need to have a higher melting or softening point than that of the thermoplastic
matrix, so that the organic abrasive particles are not substantially affected by the filament
manufacturing process. The organic abrasive particle should be capable of maintaining a
generally particulate state during filament or brush segment processing, and therefore
should be selected so as not to substantially melt or soften during the filament
manufacturing process. In one preferred embodiment, the organic particles are selected to
provide greater abrasive properties than the thermoplastic matrix, if present. In this manner,
the organic abrasive particles will perform the desired surface refinement, such as
removing foreign material from the workpiece or providing a fine surface finish, while the
thermoplastic matrix wears away during operation to continuously present fresh organic
abrasive particles to the workpiece surface.

There are several ways to form a thermoplastic abrasive particle. One such method
is to extrude the thermoplastic polymer into elongate segments and then cut these
segments into the desired length. Alternatively, the thermoplastic material can be molded
into the desired shape and particle size. This molding process can be compression
molding or injection molding.

The organic abrasive particles may be formed from a thermosetting polymer.
Thermosetting polymers may be selected from phenolic resins, aminoplast resins, urethane
resins, epoxy resins, acrylate resins, acrylated isocyanurate resins, ureaformaldehyde
resins, isocyanurate resins, acrylated urethane resins, melamine formaldehyde resins,
acrylated epoxy resins, and combinations of two or more thereof.

The organic abrasive particles used herein also may be formed from a mixture of a
thermoplastic polymer and a thermosetting polymer.
Also in accordance to the present disclosure, the abrasive particles comprised in the composition may be a mixture of inorganic abrasive particles and organic particles.

In accordance to the present disclosure, the abrasive particles may be present in the composition at a level of about 10-40 wt%, or about 20-40 wt%, or about 25-40 wt%.

The abrasive filaments disclosed herein may be prepared by any suitable process, such as melt spinning processes. For example, the abrasive filaments may be prepared by a continuous melt spinning process, in which all components of the polyamide composition without the abrasive particles disclosed herein are blended together and then the blend is passed through an extruder (e.g., a twin-screw extruder) with the abrasive particles being added into the extruder through a side feeder and melt spun into filaments. Or, the abrasive filaments may be prepared by a two-step melt spinning process, in which all components of the polyamide composition without the abrasive particles are first melt compounded into resin pellets, and then the resin pellets are passed through an extruder (e.g., a twin-screw extruder), with the abrasive particles being added into the extruder through a side feeder, and melt spun into filaments.

As demonstrated by the examples below, before adding the abrasive particles, the base polyamide (e.g., polyamide 6,1 0) has a relatively low flexural modulus (e.g., 1548.8 MPa) (CE1). However, with the addition of the linear chain extending compound, along with the antioxidant, the flexural modulus of the base polyamide composition is greatly improved (an about 25% improvement, see E1). However, by adding branched chain extending additive (such as polycarbodiimide), the density of the base polyamide composition becomes too low to be processable and usable in practice (see CE2).

Further disclosed herein are industrial brushes comprising the abrasive filaments disclosed hereabove. The industrial brushes disclosed herein may be used for the grinding and/or polishing of silicon ingot, stone, or metal parts. In one embodiment, the industrial brushes disclosed herein are used for polishing silicon ingot. When used in polishing silicon ingots, industrial brushes comprising prior art abrasive filaments often cause severe end-rounding at the longitudinal end of the ingots and therefore decreases the production rate of silicon wafers. However, due to the improved flexural modulus or stiffness of the
base polyamide composition that is used in the abrasive filaments disclosed herein, the end-rounding effect could be reduced and therefore the production rate of silicon wafers could be improved.

EXAMPLES

Material:
- **PA610-1**: a polyamide 6,10 having a relative viscosity (RV) of 2.73 and obtained from DuPont-Xingda Filaments Co. Ltd. (China) under trade name Herox®;
- **PA610-2**: a polyamide 6,10 having a RV of 2.35 and obtained from DuPont-Xingda Filaments Co. Ltd. (China) under trade name Herox®;
- **PA612**: a polyamide 6,12 having a RV of 2.5 and obtained from E.I. du Pont de Nemours and Company (U.S.A.) (hereafter "DuPont") under trade name Zytel®;
- **AO**: an antioxidant (N,N'-hexane-1,6-diylbis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide))) obtained from BASF (Germany) under trade name Irganox®1098;
- **LCEC**: a linear chain extending compound (N,N'-carbonyl bisscaprolactam) obtained from DSM (Netherland) under the trade name ALLINCO™;
- **BCEA**: a branched chain extending additive (polycarbodiimide) obtained from Rhein Chemie (Germany) under the trade name Stabaxol™ P400;
- **AP (abrasive particles)**: silicon carbide grits obtained from Jiangyan Dongyin Grinding Materials and Tools Co. Ltd. (China).

Test Methods:
- **RV** (relative viscosity) was measured using ViscoSystem™ AVS 370 viscometer purchased from S1 Analytics GmbH (Germany), wherein the test sampled were dissolved in a 98% sulfuric acid solution;
- **MT** (melt temperature) was measured using a Q100 Differential Scanning Calorimeter (DSC) (purchased from Texas Instruments (U.S.A.)) with the temperature ramp from 40°C to 280°C at a rate of 10°C/min;
• Tensile (tensile strength at break) was measured in accordance to ISO 527-2;
• EAB (elongation at break) was measured in accordance to ISO 527-2;
• FM (flexural modulus) was measured in accordance to ISO 178;
• Izod (Izod impact strength) was measured in accordance to ISO 180;
• Density was measured using an electronic densimeter SD-200L (purchased from Alfa Mirage Co. Ltd. (Japan)).

Comparative Examples CE1-CE6 and Example E1:

All components contained in each of the polyamide compositions in Examples E1 and Comparative Examples CE1-CE6 and the amounts present are listed in Table 1 below. First, in each of CE2-E6 and E1, resin pellets comprising all components except abrasive particles were prepared by extrusion using a ZSK-30 twin-screw extruder (purchased from Coperion Werner & Pfleiderer GmbH & Co. (Germany)) with the extruder temperature set at 240-280°C, the extrusion speed at 300 rpm, and the throughput at 30 lb/hr. The RV for each of the resin pellets used in CE2-CE6 and E1 and the PA610-1 pellets used in CE1 were determined and the results are tabulated in Table 1. Thereafter, the resin pellets used in CE2-CE6 and E1 and the PA610-1 pellets used in CE1 were each molded into test specimens and the tensile strength at break, elongation at break, flexural modulus, and Izod impact strength thereof were determined and tabulated in Table 1. The test specimens used in these measurements were molded using a 180 ton injection molding machine purchased from Sumitomo Plastic Machinery (Japan) with a molding temperature set at about 250-260°C.

Finally, the resin pellets in each of CE1-CE6 and E1, along with 30 wt% of abrasive particles, were fed into a twin-screw extrusion spinning line to form filaments. The resin pellets were fed through the main feeder while the abrasive particles were fed through a side feed of the extruder and the extruder temperature was set at 240°-280°C. The density of the filaments were then determined and the results are tabulated in Table 1.

As it is shown here, before adding Abrasive Particles, PA610-1 has a relatively low flexural modulus (e.g., 1548.8 MPa) (CE1). However, with the addition of Linear Chain
Extending Compound, along with Antioxidant, the flexural modulus of the base polyamide composition is greatly improved (an about 25% improvement, see E1). However, by adding Branched Chain Extending Additive, the density of the base polyamide composition becomes too low to be processable and usable in practice (see CE2).

### TABLE 1

<table>
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<tr>
<th>Property</th>
<th>CE1</th>
<th>CE2</th>
<th>CE3</th>
<th>CE4</th>
<th>CE5</th>
<th>CE6</th>
<th>E1</th>
</tr>
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<tr>
<td>Composition</td>
<td>PA610-1 (wt%)</td>
<td>70</td>
<td>69.3</td>
<td>69.44</td>
<td>69.72</td>
<td>69.58</td>
<td>69.44</td>
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<tr>
<td>AO (wt%)</td>
<td>-</td>
<td>-</td>
<td>0.56</td>
<td>0.28</td>
<td>-</td>
<td>-</td>
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<tr>
<td>LCEC (wt%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.42</td>
<td>0.56</td>
<td>0.28</td>
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<td>BCEA (wt%)</td>
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<td>-</td>
<td>-</td>
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<td>AP (wt%)</td>
<td>30</td>
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</table>

Notes: The measurements of RV, MT, Tensile, EAB, FM, and Izod were obtained using the compositions without AP.

### Comparative Examples CE7-CE8 and Example E2-E4:

Similarly to E1 and CE2-CE6, the polyamide resin pellets used in E2-E4 and CE7-CE8 were prepared. The RV for each of the resin pellets used in E2-E4 and CE7-CE8 were determined and the results are tabulated in Table 2. Thereafter, the resin pellets used in E2-E4 and CE7-CE8 were molded into test specimens (as described above) and the tensile strength at break, elongation at break, flexural modulus, and Izod impact strength thereof were determined and tabulated in Table 2.
Again, as demonstrated herein, by adding Linear Chain Extending Compound and Antioxidant simultaneously into PA612, the flexural modulus therefore (E2) is improved compared to that of the PA612 compositions containing the Antioxidant (CE7) alone or that of the PA612 composition containing the Linear Chain Extending Compound alone (CE8).

TABLE 2

<table>
<thead>
<tr>
<th>Composition</th>
<th>CE7</th>
<th>CE8</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
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<tr>
<td>PA612 (wt%)</td>
<td>99.6</td>
<td>99.6</td>
<td>99.2</td>
<td>49.6</td>
<td>-</td>
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<tr>
<td>AO (wt%)</td>
<td>0.4</td>
<td>-</td>
<td>0.4</td>
<td>0.4</td>
<td>0.6</td>
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<tr>
<td>LCEC (wt%)</td>
<td>-</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.6</td>
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<tr>
<td>PA610-2 (wt%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>49.6</td>
<td>98.8</td>
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<tr>
<td>Property</td>
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</tr>
<tr>
<td>RV</td>
<td>2.69</td>
<td>2.86</td>
<td>2.79</td>
<td>2.63</td>
<td>2.51</td>
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<tr>
<td>MT (°C)</td>
<td>214.4</td>
<td>215.4</td>
<td>214.9</td>
<td>222.1</td>
<td>223.9</td>
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<tr>
<td>Tensile (MPa)</td>
<td>2209.5</td>
<td>2261.8</td>
<td>2200.5</td>
<td>1866.3</td>
<td>2081</td>
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<tr>
<td>EOB (%)</td>
<td>137.9</td>
<td>146.9</td>
<td>195.8</td>
<td>319.7</td>
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<td>FM (MPa)</td>
<td>2131.0</td>
<td>2045.9</td>
<td>2151.2</td>
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<td>Izod (KJ/m²)</td>
<td>5.47</td>
<td>5.43</td>
<td>5.50</td>
<td>6.29</td>
<td>5.59</td>
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</table>
WHAT IS CLAIMED IS:

1. An abrasive filament formed of a melt blended polyamide composition, wherein the polyamide composition comprises:
   (i) at least one polyamide;
   (ii) 0.1 - 1 wt% of at least one linear chain extending compound having a molecular weight of 1000 Daltons or lower;
   (iii) 0.1 - 1 wt% of at least one antioxidant; and
   (iv) 10-40 wt% of abrasive particles,
   with the total wt% of all components in the composition totaling to 100 wt%.

2. The abrasive filament of Claim 1, wherein the at least one linear chain extending compound is selected from the group consisting of bis-lactam compounds, bis-oxazoline compounds, bis-oxazine compounds, and combinations of two or more thereof, or preferably, the bis-lactam compounds are selected from the group consisting of N,N'-isophthaloyl bis-caprolactam; N,N'-adipoyl bis-caprolactam; N,N'-terephthaloyl bis-laurolactam; N,N'-isophthaloyl bis-butyrolactam; carbonyl bis-caprolactam; and combinations of two or more thereof, and the bis-oxazoline compounds and bis-oxazine compounds are selected from the group consisting of 2,2'-bis(2-oxazoline); 2,2-bis(4-methyl-2-oxazoline); 2,2'-bis(4-phenyl-2-oxazoline); 2,2'-bis(4-hexyloxazoline); 2,2'-p-phenylene bis(2-oxazoline); 2,2'-m-phenylene bis(2-oxazoline); 2,2'-tetramethylene bis(4,4'-dimethyl-2-oxazoline); the corresponding oxazines; and combinations of two or more thereof, or more preferably, the at least one linear chain extending compound is carbonyl bis-caprolactam.

3. The abrasive filament of Claim 1 or 2, wherein the at least one linear chain extending compound is present in the polyamide composition at a level of 0.2-0.7 wt%, based on the total weight of the polyamide composition.
4. The abrasive filament of any of Claims 1-3, wherein the at least one antioxidant is selected from sterically hindered phenols, or preferably, the at least one antioxidant is selected from the group consisting of pentaerythritol tetrakis (3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate; 3,3',3',5,5',5'-hexa-tert-butyl-a,a',a'-(mesitylene-2,4-,6-triyl)tri-p-cresol; N,N'-hexane-1,6-diylbis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide)); octadecyl-3-(3,5-di-tert.butyl-4-hydroxyphenyl)propionate; and combinations of two or more thereof, or more preferably, the at least one antioxidant is N,N'-hexane-1,6-diylbis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide).

5. The abrasive filament of any of Claims 1-4, wherein the at least one antioxidant is present in the polyamide composition at a level of 0.2-0.7 wt%, based on the total weight of the polyamide composition.

6. The abrasive filament of any of Claims 1-5, wherein the abrasive particles are selected from the group consisting of organic abrasive particles, inorganic abrasive particles, and combinations thereof, or preferably, the abrasive particles are selected from the group consisting of particles based on aluminum oxides, alpha alumina, silicon carbides, titanium diborides, alumina zirconia, diamond, boron carbide, ceria, aluminum silicates, cubic boron nitride, garnet, silica, pumice, sand, emery, mica, corundum, quartz, and combinations of two or more thereof.

7. The abrasive filament of any of Claims 1-6, wherein the at least one polyamide is selected from aliphatic polyamides, or preferably, the at least one polyamide is selected from the group consisting of polyamide 4,6; polyamide 6; polyamide 6,6; polyamide 6,10; polyamide 6,12; polyamide 6,13; polyamide 6,14; polyamide 6,15; polyamide 6,16; polyamide 9,10; polyamide 9,12; polyamide 9,13; polyamide 9,14; polyamide 9,15; polyamide 9,36; polyamide 10,10; polyamide 10,12; polyamide 10,13; polyamide 10,14; polyamide 11; polyamide 12; polyamide 12,10; polyamide

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12,12; polyamide 12,13; polyamide 12,14; and combinations of two or more thereof, or more preferably, the at least one aliphatic polyamide is selected from polyamide 6,10; polyamide 6,12; and combinations thereof.

8. The abrasive filaments of any of Claims 1-7, wherein the at least one polyamide has a relative viscosity of 2.3-5, or preferably 2.3-4, or more preferably 2.3-3.5.

9. The abrasive filament of any of Claims 1-8, wherein the at least one polyamide is present in the polyamide composition at a level of 60-90 wt%, or preferably 60-80 wt%, or more preferably 60-75 wt%, based on the total weight of the polyamide composition.

10. The abrasive filament of any of Claims 1-9, wherein the abrasive filament is prepared by a continuous melt spinning process, and wherein the process comprises:
   (i) blending the at least one polyamide, the at least one linear chain extender compound, and the at least one antioxidant into a mixture;
   (ii) passing the mixture through an extruder while the abrasive particles are added into the extruder through one or more side feeders; and
   (iii) melt spinning the composition that comes out of the extruder into filaments.

11. The abrasive filament of any of Claims 1-9, wherein the abrasive filament is prepared by a two-step melt spinning process, and wherein the process comprises:
   (i) melt compounding the at least one polyamide, the at least one linear chain extender compound, and the at least one antioxidant into resin pellets;
   (ii) passing the resin pellets through an extruder while the abrasive particles are added into the extruder through one or more side feeders; and
   (iii) melt spinning the composition that comes out of the extruder into filaments.

13. The use of the industrial brush of Claim 12 in grinding and/or polishing silicon ingots, stone, or metal parts, or preferably the use in grinding and/or polishing silicon ingots.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. D91 F1/10 D01 FB/60 A46D 1/QG B08B1/09 D01D1/G6

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)
D01 F A46D B08B D01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>A</td>
<td>WO 2010/03367 1 Al (DU PONT [US] ; LIU XIANQIAO [CN] ; SUN NANJIAN [CN] ; YU TING [CN] ; WANG) 25 March 2010 (2010-03-25) cited in the application abstract ; claims 3, 4, 6, 9 ; examples 1, 2 page 5, line 26 - page 6, line 4</td>
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<td>A</td>
<td>DE 100 42 176 AI (BAYER AG [DE]) 13 September 2001 (2001-09-13) abstract ; claim 1 page 6, lines 44-5</td>
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* 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
"L" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"P" document published prior to the international filing date but later than the priority date claimed

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"Z" document member of the same patent family

Date of the actual completion of the international search 1 February 2013

Date of mailing of the international search report 08/02/2013

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Malik, Jan
<table>
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<td>CN 101 994 167 A (CITY JIEDA) NANOMETER COMPOUNDED MATERIALS CO LTD) 30 March 2011 (2011-03-30) abstract</td>
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