

Low-Halogen Flame Retardant Polyamide Compositions Resistant to Heat Aging

Background of the Invention

[0001] Polyamide resins are desirable for use in many applications due to their high melting points, high recrystallization temperatures (*i.e.*, faster injection molding cycle times), high flow, toughness, elasticity, chemical resistance, inherent UL94 V2 flame retardancy and abrasion resistance. These chemical and mechanical properties make polyamides ideal for use in such diverse applications as cable ties, sports equipment, window thermal breaks, aerosol valves, food film packaging, automotive/vehicle parts (*e.g.*, radiator endtanks, charge air coolers, fans and shrouds, push/pull cables), industrial fibers (*e.g.*, airbags, tire cords) and electrical/electronic parts (*e.g.*, connectors, terminal blocks, battery seals, photovoltaics, LEDs, circuit breakers).

[0002] Historically, halogen-based flame retardants have been primarily added to thermoplastic compositions to achieve desired flame retardancy ratings where the flame retardants were predominantly either chlorine-based or bromine-based. The flame retardant acts in the solid, liquid or gas phase chemically (*e.g.*, by liberation of nitrogen gas) and/or mechanically (*e.g.*, by producing a foam). Flame retardants typically interfere with a specific stage of the combustion process, such as during heating, decomposition, ignition or flame spread.

[0003] Examples of conventional chlorine-based flame retardants include chlorinated paraffins, chlorinated polyethylenes, dodecachloropentacyclooctadeca-7,15-diene (Dechlorane Plus® 25) and HET anhydride. Examples of conventional bromine-based flame retardants include hexabromocyclododecane (HBCD), decabromodiphenyl oxide (DBDPO), octabromodiphenyl oxide, tetrabromobisphenol A (TBBA), bis(tribromophenoxy)ethane, bis(pentabromophenoxy)ethane (BPBPE), tetrabromobisphenol A epoxy resins (TBBA epoxy), tetrabromobisphenol A carbonates (TBBA-PC), ethylene(bistetabromophthal)imide (EBTBPI), ethylenebis(pentabromodiphenyl), tris(tribromophenoxy)triazine (TTBPTA), bis(dibromopropyl)tetrabromobisphenol A (DBP-TBBA), bis(dibromopropyl)tetrabromobisphenol S (DBP-TBBS), brominated polyphenylene ethers (BrPPE) (such as poly(di)bromophenylene ethers, *etc.*), brominated polystyrenes (BrPPE) (such as polydibromostyrene, polytribromostyrene, crosslinked brominated polystyrenes, *etc.*), brominated crosslinked aromatic polymers, brominated epoxy resins, brominated

phenoxy resins, brominated styrene-maleic anhydride polymers, tetrabromobisphenol S (TBBS), tris(tribromoneopentyl)phosphate (TTBNPP), polybromotrimethylphenylindan (PBPI) and tris(dibromopropyl)-isocyanurate (TDBPIC).

[0004] When considering the choice of a halogen-based flame retardant for incorporation into a thermoplastic material, key requirements include minimal generation of corrosive gases during melt processing of the thermoplastic material, such as during extrusion and molding and the maintenance of the thermoplastic material's flame resistance and mechanical properties. Examples of halogen-based flame retardants that satisfy these requirements include brominated polyphenylene ethers (including poly(di)bromophenylene ether, *etc.*) and brominated polystyrenes (including polydibromostyrene, polytribromostyrene, crosslinked brominated polystyrene, *etc.*), with brominated polystyrenes typically being the most preferred.

[0005] Halogen-based flame retardants are also historically accompanied by one or more flame retardant synergists. Conventional flame retardant synergists include antimony oxides (such as diantimony trioxide, diantimony tetroxide, diantimony pentoxide and sodium antimonate), tin oxides (such as tin monoxide and tin dioxide), iron oxides (such as iron(II) oxide and γ -iron oxide), zinc oxide and zinc borate.

[0006] Due to environmental concerns, non-halogen-based and low-halogen-based flame retardant additives have increasingly become more prevalent in thermoplastics, especially in polyamides. These additives utilize nitrogen- and phosphorus-based chemical mechanisms for achieving the desired degree of flame retardancy.

[0007] Conventional phosphorus-based, non-halogen flame retardants include phosphinates, such as calcium dimethylphosphinate, magnesium dimethylphosphinate, aluminum dimethylphosphinate, zinc dimethylphosphinate, calcium ethylmethylphosphinate, magnesium ethylmethylphosphinate, aluminum ethylmethylphosphinate, zinc ethylmethylphosphinate, calcium diethylphosphinate, magnesium diethylphosphinate, aluminum diethylphosphinate, zinc diethylphosphinate, calcium methyl-n-propylphosphinate, magnesium methyl-n-propylphosphinate, aluminum methyl-n-propylphosphinate, zinc methyl-n-propylphosphinate, calcium methylenebis(methylphosphinate), magnesium methylenebis(methylphosphinate), aluminum methylenebis(methylphosphinate), zinc methylenebis(methylphosphinate), calcium phenylene-1,4-bis(methylphosphinate), magnesium phenylene-1,4-

bis(methylphosphinate), aluminum phenylene-1,4-bis(methylphosphinate), zinc phenylene-1,4-bis(methylphosphinate), calcium methylphenylphosphinate, magnesium methylphenylphosphinate, aluminum methylphenylphosphinate, zinc methylphenylphosphinate, calcium diphenylphosphinate, magnesium diphenylphosphinate, aluminum diphenylphosphinate and zinc diphenylphosphinate.

[0008] Conventional nitrogen-based, non-halogen flame retardants include benzoguanamine, tris(hydroxyethyl)isocyanurate, isocyanurate, allantoin, glycoluril, melamine cyanurate, melamine phosphate, dimelamine phosphate, melamine pyrophosphate, urea cyanurate, melamine polyphosphate, melamine borate, ammonium polyphosphate, melamine ammonium polyphosphate, melamine ammonium pyrophosphate and condensation products of melamine (such as melem, melam, melon and higher condensed compounds).

[0009] Heat stabilizers may be employed in polyamide resins. Conventional heat stabilizers include those selected from hindered phenolic stabilizers, phosphite-based stabilizers, hindered amine-based stabilizers, triazine-based stabilizers, sulfur-based stabilizers and copper stabilizers.

[00010] Examples of hindered phenolic stabilizers include N,N'-hexane-1,6-diylbis[3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide]; pentaerythrityl-tetrakis[3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate]; N,N'-hexamethylenebis(3,5-di-tert-butyl-4-hydroxy-hydrocinnamamide); triethyleneglycol-bis[3-(3-tert-butyl-5-methyl-4-hydroxyphenyl)propionate]; 3,9-bis{2-[3-(3-tert-butyl-4-hydroxy-5-methylphenyl)propionyloxy]-1,1-dimethylethyl}-2,4,8,10-tetraoxaspiro[5,5]undecane; 3,5-di-tert-butyl-4-hydroxybenzylphosphonate-diethyl ester; 1,3,5-trimethyl-2,4,6-tris(3,5-di-tert-butyl-4-hydroxybenzyl)benzene; and 1,3,5-tris(4-tert-butyl-3-hydroxy-2,6-dimethylbenzyl)isocyanurate.

[00011] Examples of phosphite-based stabilizers include trioctyl phosphite; trilauryl phosphite; tridecyl phosphite; octyldiphenyl phosphite; trisisodecyl phosphite; phenyl diisodecyl phosphite; phenyl di(tridecyl)phosphite; diphenyl isooctyl phosphite; diphenyl isodecyl phosphite; diphenyl(tridecyl)phosphite; triphenyl phosphite; tris(nonylphenyl)phosphite; tris(2,4-di-tert-butylphenyl)phosphite; tris(2,4-di-tert-butyl-5-methylphenyl)phosphite; tris(butoxyethyl)phosphite; 4,4'-butylidene-bis(3-methyl-6-tert-butylphenyl-tetra-tridecyl)diphosphite; tetra(C₁₂- to C₁₅- mixed alkyl)-4,4'-

isopropylidenediphenyl diphosphite; 4,4'-isopropylidenebis(2-tert-butylphenyl)-di(nonylphenyl)phosphite; tris(biphenyl)phosphite; tetra(tridecyl)-1,1,3-tris(2-methyl-5-tert-butyl-4-hydroxyphenyl)butane diphosphite; tetra(tridecyl)-4,4'-butylidenebis(3-methyl-6-tert-butylphenyl)diphosphite; tetra(C₁- to C₁₅- mixed alkyl)-4,4'-isopropylidenediphenyl diphosphite; tris(mono-/di- mixed nonylphenyl)phosphite; 4,4'-isopropylidenebis(2-tert-butylphenyl)-di(nonylphenyl)phosphite; 9,10-di-hydro-9-oxa-10-phosphorphenanthrene-10-oxide; tris(3,5-di-*t*-butyl-4-hydroxyphenyl)phosphite; hydrogenated-4,4'-isopropylidenediphenyl polyphosphite; bis(octylphenyl)-bis(4,4'-butylidenebis(3-methyl-6-tert-butylphenyl)-1,6-hexanol diphosphite; hexa(tridecyl)-1,1,3-tris(2-methyl-4-hydroxy-5-tert-butylphenyl)butane triphosphite; tris(4,4'-isopropylidenebis(2-tert-butylphenyl)phosphite; tris(1,3-stearyloxyisopropyl)phosphite; 2,2-methylenebis(4,6-di-tert-butylphenyl)octyl phosphite; 2,2-methylenebis(3-methyl-4,6-di-tert-butylphenyl)-2-ethylhexyl phosphite; tetrakis(2,4-di-tert-butyl-5-methylphenyl)-4,4'-biphenylene diphosphite; and tetrakis(2,4-di-tert-butylphenyl)-4,4'-biphenylene diphosphite.

[00012] Conventional phosphite-based stabilizers also include pentaerythritol-type phosphite compounds, such as 2,6-di-tert-butyl-4-methylphenyl-phenyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-methyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-2-ethylhexyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-isodecyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-lauryl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-isotridecyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-stearyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-cyclohexyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-benzyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-ethylcellosolve-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-butylcarbitol-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-octylphenyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-nonylphenyl-pentaerythritol diphosphite; bis(2,6-di-tert-butyl-4-methylphenyl)pentaerythritol diphosphite; bis(2,6-di-tert-butyl-4-ethylphenyl)pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-2,6-di-tert-butylphenyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-2,4-di-tert-butylphenyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-2,4-di-tert-octylphenyl-pentaerythritol diphosphite; 2,6-di-tert-butyl-4-methylphenyl-2-cyclohexylphenyl-pentaerythritol diphosphite; 2,6-di-tert-amyl-4-methylphenyl-phenyl-

pentaerythritol diphosphite; bis(2,6-di-tert-amyl-4-methylphenyl)pentaerythritol diphosphite; and bis(2,6-di-tert-octyl-4-methylphenyl)pentaerythritol diphosphite.

[00013] Examples of hindered amine-based stabilizers include 4-acetoxy-2,2,6,6-tetramethylpiperidine; 4-stearoyloxy-2,2,6,6-tetramethylpiperidine; 4-acryloyloxy-2,2,6,6-tetramethylpiperidine; 4-(phenylacetoxy)-2,2,6,6-tetramethylpiperidine; 4-benzoyloxy-2,2,6,6-tetramethylpiperidine; 4-methoxy-2,2,6,6-tetramethylpiperidine; 4-stearyloxy-2,2,6,6-tetramethylpiperidine; 4-cyclohexyloxy-2,2,6,6-tetramethylpiperidine; 4-benzyloxy-2,2,6,6-tetramethylpiperidine; 4-phenoxy-2,2,6,6-tetramethylpiperidine; 4-(ethylcarbamoyloxy)-2,2,6,6-tetramethylpiperidine; 4-(cyclohexylcarbamoyloxy)-2,2,6,6-tetramethylpiperidine; 4-(phenylcarbamoyloxy)-2,2,6,6-tetramethylpiperidine; bis(2,2,6,6-tetramethyl-4-piperidyl)-carbonate; bis(2,2,6,6-tetramethyl-4-piperidyl)-oxalate; bis(2,2,6,6-tetramethyl-4-piperidyl)-malonate; bis(2,2,6,6-tetramethyl-4-piperidyl)-sebacate; bis(2,2,6,6-tetramethyl-4-piperidyl)-adipate; bis(2,2,6,6-tetramethyl-4-piperidyl)-terephthalate; 1,2-bis(2,2,6,6-tetramethyl-4-piperidyloxy)-ethane; α,α' -bis(2,2,6,6-tetramethyl-4-piperidyloxy)-p-xylene; bis(2,2,6,6-tetramethyl-4-piperidyl)-tolylene-2,4-dicarbamate; bis(2,2,6,6-tetramethyl-4-piperidyl)-hexamethylene-1,6-dicarbamate; tris(2,2,6,6-tetramethyl-4-piperidyl)-benzene-1,3,5-tricarboxylate; tris(2,2,6,6-tetramethyl-4-piperidyl)-benzene-1,3,4-tricarboxylate; 1-[2-{3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionyloxy}butyl]-4-[3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionyloxy]2,2,6,6-tetramethylpiperidine; and a condensation product of 1,2,3,4-butanetetracarboxylic acid; 1,2,2,6,6-pentamethyl-4-piperidinol; and $\beta,\beta,\beta',\beta'$ -tetramethyl-3,9-[2,4,8,10-tetraoxaspiro(5,5)undecane]diethanol.

[00014] Examples of conventional triazine-based stabilizers include 2,4,6-tris(2'-hydroxy-4'-octyloxy-phenyl)-1,3,5-triazine; 2-(2'-hydroxy-4'-hexyloxy-phenyl)-4,6-diphenyl-1,3,5-triazine; 2-(2'-hydroxy-4'-octyloxyphenyl)-4,6-bis(2',4'-dimethylphenyl)-1,3,5-triazine; 2-(2',4'-dihydroxyphenyl)-4,6-bis(2',4'-dimethylphenyl)-1,3,5-triazine; 2,4-bis(2'-hydroxy-4'-propyloxy-phenyl)-6-(2',4'-dimethylphenyl)-1,3,5-triazine; 2-(2-hydroxy-4-octyloxyphenyl)-4,6-bis(4'-methylphenyl)-1,3,5-triazine; 2-(2'-hydroxy-4'-dodecyloxyphenyl)-4,6-bis(2',4'-dimethylphenyl)-1,3,5-triazine; 2,4,6-tris(2'-hydroxy-4'-isopropyloxyphenyl)-1,3,5-triazine; 2,4,6-tris(2'-hydroxy-4'-n-hexyloxyphenyl)-1,3,5-triazine; and 2,4,6-tris(2'-hydroxy-4'-ethoxycarbonylmethoxyphenyl)-1,3,5-triazine.

[00015] Conventional copper stabilizers include copper halides (*e.g.*, chlorides, bromides, iodides), copper acetate, copper propionate, copper benzoate, copper adipate, copper terephthalate, copper isophthalate, copper salicylate, copper nicotinate, copper stearate, and copper complex salts coordinated to a chelating amine such as ethylenediamine and ethylenediaminetetraacetic acid.

[00016] In the automotive industry, there is an environmental-driven need to reduce emissions and to increase the efficiency of fuel consumption. One way of achieving these goals is to reduce the overall vehicle weight by substituting metal components with thermoplastic ones. Polyamides provide ideal weight reduction in the engine compartment due to their aforementioned heat resistance, mechanical strength, and overall appearance. Coinciding with vehicle weight reduction is the trend to use turbochargers to improve fuel efficiency which increases the demand for polyamides with even higher heat resistance that can also satisfy the mechanical/structural requirements for this application. Along with targeting higher heat resistance, the automotive industry is utilizing more flame retardant thermoplastics. The polyamide compositions of the present invention were developed in part to address these demands for higher heat resistance and flame retardancy while also achieving the desired overall reduction in weight necessary to succeed in the automotive industry.

[00017] The polyamide compositions of the present invention are also highly suitable for use in the electrical/electronic industry where the trend toward integration of electronic components has led to an increasing need for the employment of plastic materials with much greater heat resistance and flame retardancy, particularly for use in connectors, circuit breakers, circuit boards and terminal blocks. Such devices are often required to run continuously in demanding environments under extreme temperatures and voltages.

[00018] Another need for high heat resistant polyamide compositions is in surface mounting technology (SMT), where the compositions must withstand the melting point of the lead-free solder and avoid bubbling or blistering during the SMT operation. The ability of the polyamide compositions of the present invention to satisfy both the flammability and electrical requirements while also providing improved heat resistance compared to conventional polyamide compositions distinguishes the polyamide compositions of the present invention and makes them ideally suited for addressing the increasingly challenging demands adopted by the electrical/electronic industry.

Summary of the Invention

- [00019]** An aspect of the present invention is a low-halogen thermoplastic polyamide composition comprising a polyamide resin; a copper-containing heat stabilizer; and a non-halogen flame retardant, where the polyamide composition exhibits superior heat stability while maintaining excellent electrical properties. In an exemplary embodiment, the polyamide composition has an elemental bromine (Br) content of greater than 900 ppm but less than 1300 ppm. In another exemplary embodiment, the polyamide composition has a maximum elemental bromine (Br) content of 900 ppm. In an exemplary embodiment, the polyamide composition also has a maximum total halogen content of 1500 ppm.
- [00020]** In an exemplary embodiment, the low-halogen thermoplastic polyamide composition comprises: a high flow polyamide resin; a non-halogen, nitrogen-containing flame retardant; and a copper-containing heat stabilizer comprising a copper halide and an organophosphorus compound.
- [00021]** In an exemplary embodiment, the heat stabilizer comprises a second copper-containing compound in addition to the copper halide/organophosphorus compound.
- [00022]** In an exemplary embodiment, the polyamide resin is selected from the group consisting of PA-4,6; PA-6,I; PA-6,T; PA-6,6; PA-6/6,6; and mixtures thereof.
- [00023]** In a particular embodiment, the polyamide resin is PA-6,6.
- [00024]** In an exemplary embodiment, the non-halogen, nitrogen-containing flame retardant is a melamine salt or a melamine complex/adduct.
- [00025]** In a particular embodiment, the melamine salt or a melamine complex/adduct is melamine cyanurate.
- [00026]** In a particular embodiment, the melamine salt or a melamine complex/adduct is melamine polyphosphate.
- [00027]** In an exemplary embodiment, the copper halide of the copper-containing heat stabilizer is a copper(I) halide and the organophosphorus compound is triphenylphosphine.
- [00028]** In an exemplary embodiment, the copper halide of the copper-containing heat stabilizer is a copper(I) halide and the organophosphorus compound is triphenylphosphite.
- [00029]** In a particular embodiment, the copper(I) halide is copper(I) iodide.
- [00030]** In a particular embodiment, the copper halide and the organophosphorus compound form a complex.

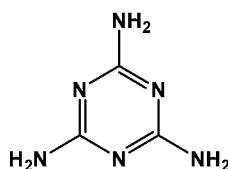
- [00031] In an exemplary embodiment, the thermoplastic polyamide composition further comprises a lubricant/mold release agent.
- [00032] In an exemplary embodiment, the lubricant/mold release agent is a stearic acid salt.
- [00033] In a particular embodiment, the stearic acid salt is selected from the group consisting of Al stearate, Zn stearate, Ca stearate and mixtures thereof.
- [00034] In an exemplary embodiment, the thermoplastic polyamide composition further comprises a colorant.
- [00035] In a particular embodiment, the colorant is carbon black.
- [00036] In an exemplary embodiment, the thermoplastic polyamide composition comprises: 50-95% (such as 55-95%, such as 60-95%, such as 65-95%) by weight of the polyamide resin; 1-30% (such as 1-20%, such as 1-15%, such as 1-10%) by weight of a melamine salt or a melamine complex/adduct as the non-halogen, nitrogen-containing flame retardant; 0.01-10% (0.01-8%, such as 0.01-5%, such as 0.01-4%, such as 0.01-3%, such as 0.01-2%, such as 0.1-8%, such as 0.1-5%, such as 0.1-4%, such as 0.1-3%, such as 0.1-2%, such as 1-8%, such as 1-5%, such as 1-4%, such as 1-3%, such as 1-2%,) by weight of a copper halide/organophosphorus complex as the heat stabilizer; 0-5% (such as 0.1-5%, such as 0.1-4%, such as 0.1 to 3%, such as 1-5%, such as 1-3%) by weight of a lubricant/mold release agent; and 0-5% (such as 0.1-5%, such as 0.1-4%, such as 0.1 to 3%, such as 1-5%, such as 1-3%) by weight of a colorant. In a particular embodiment, the polyamide resin is PA-6,6. In a particular embodiment, the copper halide/organophosphorus complex is a complex of a copper(I) halide with bis(triphenylphosphine). In a particular embodiment, the melamine salt or melamine complex/adduct is melamine cyanurate or melamine polyphosphate. In an exemplary embodiment, the lubricant/mold release agent is a stearic acid salt. In a particular embodiment, the stearic acid salt is zinc stearate. In a particular embodiment, the colorant is carbon black.
- [00037] Another aspect of the invention is an article obtained from the thermoplastic polyamide compositions described herein. In an exemplary embodiment, the article is an automotive part or an electric/electronic part.

Detailed Description of the Invention

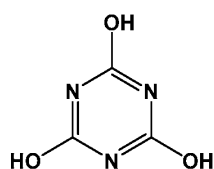
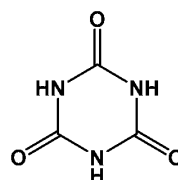
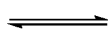
- [00038] In an exemplary embodiment, the polyamide resin is present in an amount of 50-95%, such as 55-95%, such as 60-95%, such as 65-95% by weight selected from the group

consisting of PA-6; PA-6,6; PA-6,10; PA-4,6; PA-11; PA-12; PA-12,12; PA-6,I; PA-6,T; PA-6,T/6,6-copolyamide; PA-6,T/6-copolyamide; PA-6/6,6-copolyamide; PA-6,6/6,T/6,I-copolyamide; PA-6,T/2-MPMDT-copolyamide; PA-9,T; PA-4,6/6-copolyamide; and mixtures and copolyamides of the aforementioned polyamides. In a particular embodiment, the polyamide (A) is selected from the group consisting of PA-4,6; PA-6,I; PA-6,T; PA-6,6; PA-6/6,6; and mixtures or a copolyamide thereof.

[00039] In an exemplary embodiment of the present invention, the non-halogen, nitrogen-containing flame retardant is melamine-based, such as a melamine salt or a melamine complex/adduct. In a particular embodiment, the non-halogen, nitrogen-containing flame retardant is 1-30%, such as 1-20%, such as 1-15%, such as 1-10% by weight of melamine cyanurate. Melamine cyanurate is a complex formed from a preferably 1:1 mixture of melamine (Formula (II)) and cyanuric acid or isocyanuric acid (Formulae (IIa) and (IIb), respectively).



Formula (II)

Formula (IIa)
(cyanuric acid)Formula (IIb)
(isocyanuric acid)

[00040] In an exemplary embodiment, melamine cyanurate is prepared via reaction of aqueous solutions of the compounds of Formula (II) with Formula (IIa) or Formula (IIb) between 90 to 100°C. Melamine cyanurate is also commercially available under several names (such as Melapur[®] MC25 (BASF), Budit[®] 315 (Budenheim), JLS-MC25 (Hangzhou JLS Flame Retardants Chemical Co.), Plastisan[®] B or Plastisan[®] S (3V)). In an exemplary embodiment, the melamine cyanurate used is Melapur[®] MC, MC 15, MC 25 or MC 50.

[00041] In an exemplary embodiment, melamine polyphosphate is a suitable non-halogen, nitrogen-containing flame retardant. In a particular embodiment, the melamine

polyphosphate used in preparing the polyamide compositions of the present invention is commercially available Melapur® 200 (BASF).

[00042] Historically, preferred heat stabilizers for polyamides have been copper iodide (alone or typically in combination with potassium iodide) or copper acetate because of their excellent resistance to heat aging. However, due to their significant negative effect on electrical properties such as dielectric strength, surface and volume resistivity, and comparative tracking index (CTI), these copper salts are not typically used in electrical/electronic applications. Further, copper salts such as copper iodide undesirably add color to the compositions in which they are present. In an exemplary embodiment of the present invention, the heat stabilizer is a copper halide in combination with an organophosphorus compound such as, for example, triphenylphosphine or triphenylphosphite. In a particular embodiment, the heat stabilizer is a copper halide complexed with triphenylphosphine or triphenylphosphite. In a particular embodiment, the heat stabilizer is copper iodide complexed with triphenylphosphine or triphenylphosphite. In a particular embodiment, the heat stabilizer is a copper iodide / bis(triphenylphosphine) complex. In a particular embodiment, the copper iodide / bis(triphenylphosphine) complex is BRUGGOLEN® H3386 (available from Brüggemann Chemical). These copper halide and organophosphorus compound combinations, when added to the polyamides described herein, unexpectedly result in polyamide compositions that exhibit superior heat stability while also maintaining excellent electrical properties, thus making the polyamide compositions of the present invention ideally suited for use in the electrical/electronic industries. As a further benefit, this combination of a copper halide and an organophosphorus compound does not discolor the polyamide composition.

[00043] In an exemplary embodiment, the amount of the copper stabilizer present in the polyamide compositions of the invention ranges from approximately 0.01 to 10% by weight, such as from 0.01-10%, such as 0.01-8%, such as 0.01-5%, such as 0.01-4%, such as 0.01-3%, such as 0.01-2%, such as 0.1-8%, such as 0.1-5%, such as 0.1-4%, such as 0.1-3%, such as 0.1-2%, such as 1-8%, such as 1-5%, such as 1-4%, such as 1-3%, such as 1-2%, such as 0.03 to 2.5% by weight, such as from 0.03 to 2.3%, such as from 0.03 to 2.0%, such as from 0.03 to 1.7%, such as from 0.03 to 1.5%, such as 0.03 to 1.2%, such as 0.03 to 1.0%, such as 0.03 to 0.8%, such as 0.03 to 0.5%, such as 0.03 to 0.1%, such as 0.03 to 0.08%, such as 0.04 to 3%, such as from 0.04 to 2.5%, such as from 0.04 to 2.3%, such as from 0.04 to 2.0%, such as

from 0.04 to 1.7%, such as from 0.04 to 1.5%, such as 0.04 to 1.2%, such as 0.04 to 1.0%, such as 0.04 to 0.8%, such as 0.04 to 0.5%, such as 0.04 to 0.1%, such as 0.04 to 0.08%, such as 0.05 to 3%, such as from 0.05 to 2.5%, such as from 0.05 to 2.3%, such as from 0.05 to 2.0%, such as from 0.05 to 1.7%, such as from 0.05 to 1.5%, such as 0.05 to 1.2%, such as 0.05 to 1.0%, such as 0.05 to 0.8%, such as 0.05 to 0.5%, such as 0.05 to 0.1%, such as 0.05 to 0.08%, such as from 0.07 to 2.5%, such as from 0.07 to 2.3%, such as from 0.07 to 2.0%, such as from 0.07 to 1.7%, such as from 0.07 to 1.5%, such as 0.07 to 1.2%, such as 0.07 to 1.0%, such as 0.07 to 0.8%, such as 0.07 to 0.5%, such as 0.07 to 0.1%, such as from 0.08 to 2.5%, such as from 0.08 to 2.3%, such as from 0.08 to 2.0%, such as from 0.08 to 1.7%, such as from 0.08 to 1.5%, such as 0.08 to 1.2%, such as 0.08 to 1.0%, such as from 0.1 to 2.5%, such as from 0.1 to 2.3%, such as from 0.1 to 2.0%, such as from 0.1 to 1.7%, such as from 0.1 to 1.5%, such as from 0.1 to 1.2%, such as from 0.1 to 1%, such as from 0.15 to 2.5%, such as from 0.15 to 2.3%, such as from 0.15 to 2.0%, such as from 0.15 to 1.7%, such as from 0.15 to 1.5%, such as 0.15 to 1.2%, such as 0.15 to 1.0%, such as 0.25 to 0.75%, such as 0.30 to 0.65% by weight.

[00044] In an exemplary embodiment, there is no or a non-significant amount of elemental fluorine (F) or elemental chlorine (Cl) present in the polyamide compositions of the invention and the amount of elemental bromine (Br) that is present is greater than zero but less than 2000 ppm, such as less than 1700 ppm, such as less than 1500 ppm, such as less than 1300 ppm, such as less than 1200 ppm, such as less than 1100 ppm, such as less than 1000 ppm, such as less than 900 ppm, such as less than 800 ppm, such as less than 700 ppm. In a particular embodiment, the amount of elemental bromine present is between 500 and 1500 ppm, such as between 500 and 1200 ppm, such as between 500 and 1000 ppm, such as between 500 and 900 ppm. In an exemplary embodiment, the amount of elemental bromine present is greater than 900 ppm but less than 1300 ppm, or alternatively, at a maximum of 900 ppm. In an exemplary embodiment, the total maximum halogen (elemental fluorine, chlorine and bromine) content in a polyamide composition of the invention is 1500 ppm and is typically determined using UL Halogen test 746H.

[00045] The optional lubricant/mold release agent suitable for use in the present invention includes, but is not limited to 0-5%, such as 0.1-5%, such as 0.1-4%, such as 0.1 to 3%, such as 1-5%, such as 1-3% long-chain fatty acids (*e.g.*, stearic acid or behenic acid), their salts (*e.g.*, Ca stearate or Zn stearate) or their ester or amide derivatives (*e.g.*,

ethylenebisstearylamine (Acrawax®), montan waxes (mixtures composed of straight-chain, saturated carboxylic acids having chain lengths of from 28 to 32 carbon atoms) or low-molecular-weight polyethylene waxes or low-molecular-weight polypropylene waxes. In an exemplary embodiment, the lubricant and/or mold-release agent is the salt of stearic acid, such as Al stearate, Zn stearate, or Ca stearate.

[00046] If desired, one or more colorants may also be added to the polyamide compositions of the present invention in an amount of 0-5%, such as 0.1-5%, such as 0.1-4%, such as 0.1 to 3%, such as 1-5%, such as 1-3% by weight to meet the aesthetic requirements of the final application. Examples of suitable colorants include those commonly used in polyamides, such as, but not limited to, inorganic pigments (such as titanium dioxide, ultramarine blue, iron oxide, zinc sulphide and carbon black), and also organic pigments (such as phthalocyanines, quinacridones and perylenes) and dyes (such as nigrosine and anthraquinones). In an exemplary embodiment, the colorant is carbon black.

Examples

Example 1. General preparation of a polyamide composition of the invention

[00047] The heat stabilizer, the lubricant/mold release agent, and the colorant were blended together in a drum tumbler, followed by mixing with the primary polyamide feedstock at the feed throat of a ZSK 40 mm twin screw extruder. The non-halogen, nitrogen-containing flame retardant was added via a side feeder and the extruder barrel temperatures ranged from 220-285° C, with a screw speed of 400 rpm, and a throughput of 100 kg/hr.

[00048] Molded articles for the determination of mechanical and thermal material properties were produced on a VanDorn 50-ton injection molding machine with cylinder temperatures of 250-285°C (from hopper to nozzle) and a mold temperature of 95°C.

[00049] The following internationally recognized standardized tests were employed for measuring various properties of the polyamide compositions of the invention and the articles prepared therefrom.

[00050] Tensile properties, stress, strain, and modulus were measured according to **ISO 527-2**.

[00051] Flexural properties, strength and modulus were measured according to **ISO 178**.

[00052] Charpy Notched Impact Strength at -30°C and +23°C was measured according to **ISO 179/1eA**.

- [00053] Charpy Unnotched Impact Strength at -30°C and +23°C was measured according to **ISO 179/1eU**.
- [00054] Izod Notched Impact Strength at +23°C was measured according to **ISO 180**.
- [00055] Heat Deflection Temperature with an applied load of 1.80 MPa was performed according to **ISO 75-2/A**.
- [00056] Heat Deflection Temperature with an applied load of 0.45 MPa was performed according to **ISO 75-2/B**.
- [00057] Polyamide composition melting points were determined according to **ISO 11357-3**.
- [00058] Relative Viscosity values were measured according to **ASTM D789**.
- [00059] Melt flow rate which measures the rate of extrusion of thermoplastics through an orifice at a prescribed temperature and load was determined according to **ISO 1133**.
- [00060] Flammability testing was conducted on samples at various thicknesses (0.4, 0.75, 1.5, and 3.0 mm) according to the **UL94 standard**.
- [00061] Glow Wire Flammability Index (GWFI) was performed on samples at various thicknesses (0.4, 0.75, 1.5, and 3.0 mm) according to **IEC 60695-2-12**.
- [00062] Glow Wire Ignition Temperature (GWIT) was performed on samples at various thicknesses (0.4, 0.75, 1.5, and 3.0 mm) according to **IEC 60695-2-13**.
- [00063] Volume Resistivity was measured according to **IEC 60093**.
- [00064] Dielectric Strength was measured according to **IEC 60243**.
- [00065] Arc Resistance was measured according to **ASTM D495**.
- [00066] Comparative Tracking Index (CTI) was measured according to both **IEC 60112** and **ASTM D3638**.
- [00067] High Amp Arc Ignition (HAI) was performed on samples at various thicknesses (0.4, 0.75, 1.5, and 3.0 mm) according to **UL 746**.
- [00068] Hot Wire Ignition (HWI) was performed on samples at various thicknesses (0.4, 0.75, 1.5, and 3.0 mm) according to **UL 746**.
- [00069] High Voltage Arc Tracking Rate (HVTR) was measured according to **UL 746**.
- [00070] Relative Thermal Index (RTI) values were obtained at various thicknesses (0.4, 0.75, 1.5, and 3.0 mm) for Electrical, Impact, and Strength criteria according to **UL 746**.
- [00071] Table 1 lists the results of standard test methods on an exemplary polyamide composition of the invention where the polyamide resin was PA-6,6 (91.4 wt%); the flame retardant was melamine cyanurate (8.0 wt%); the heat stabilizer was a Cu(I) iodide-

bis(triphenylphosphine) complex (0.5 wt%); and the lubricant/mold release agent was Zn stearate (0.1 wt%) (hereinafter referred to as Example 1).

Table 1.

Physical Property of Example 1 Tested	Value	Unit	Test Method
Relative Viscosity	36		ASTM D789
Mechanical Property			
Tensile Modulus (23°C)	3300	MPa	ISO 527-2
Tensile Stress (Yield, 23°C)	83	MPa	ISO 527-2
Tensile Stress (Break, 23°C)	83	MPa	ISO 527-2
Tensile Strain (Yield, 23°C)	4	%	ISO 527-2
Tensile Strain (Break, 23°C)	6	%	ISO 527-2
Flexural Modulus (23°C)	3900	MPa	ISO 178
Flexural Strength (23°C)	107	MPa	ISO 178
Impact Property			
Charpy Notched Impact Strength (-30°C)	3.7	kJ/m ²	ISO 179/1eA
Charpy Notched Impact Strength (23°C)	3.4	kJ/m ²	ISO 179/1eA
Charpy Unnotched Impact Strength (-30°C)	78	kJ/m ²	ISO 179/1eU
Charpy Unnotched Impact Strength (23°C)	75	kJ/m ²	ISO 179/1eU
Notched Izod Impact Strength (23°C)	6	kJ/m ²	ISO 180
Thermal Property			
Heat Deflection Temperature (0.45 MPa, Unannealed)	240	°C	ISO 75-2/B
Heat Deflection Temperature (1.8 MPa, Unannealed)	75	°C	ISO 75-2/A
Melting Temperature	265	°C	ISO 11357-3
RTI Elec (0.400 mm)	150	°C	UL 746
RTI Elec (0.750 mm)	150	°C	UL 746
RTI Elec (1.50 mm)	150	°C	UL 746

RTI Elec (3.00 mm)	150	°C	UL 746
RTI Imp (0.400 mm)	110	°C	UL 746
RTI Imp (0.750 mm)	110	°C	UL 746
RTI Imp (1.50 mm)	110	°C	UL 746
RTI Imp (3.00 mm)	110	°C	UL 746
RTI Str (0.400 mm)	130	°C	UL 746
RTI Str (0.750 mm)	130	°C	UL 746
RTI Str (1.50 mm)	130	°C	UL 746
RTI Str (3.00 mm)	130	°C	UL 746
Electrical Property			
Volume Resistivity (0.750 mm)	1.00E+19	ohm·cm	IEC 60093
Dielectric Strength (1.00 mm)	20	kV/mm	IEC 60243
Arc Resistance (3.00 mm)	5	PLC	ASTM D495
Comparative Tracking Index (3.00 mm)	600	V	IEC 60112
Comparative Tracking Index (3.00 mm)	0	PLC	ASTM D3638
High Amp Arc Ignition (HAI) (0.400 mm)	0	PLC	UL 746
High Amp Arc Ignition (0.750 mm)	0	PLC	UL 746
High Amp Arc Ignition (1.50 mm)	0	PLC	UL 746
High Amp Arc Ignition (3.00 mm)	0	PLC	UL 746
High Voltage Arc Tracking Rate (HVTR)	0	PLC	UL 746
Hot-wire Ignition (HWI) (0.400 mm)	4	PLC	UL 746
Hot-wire Ignition (0.750 mm)	3	PLC	UL 746
Hot-wire Ignition (1.50 mm)	3	PLC	UL 746
Hot-wire Ignition (3.00 mm)	1	PLC	UL 746
Flammability Property			
Flammability (UL Rating) (0.200 mm)	V-0		UL 94
Flammability (UL Rating) (0.400 mm)	V-0		UL 94
Flammability (UL Rating) (0.750 mm)	V-0		UL 94
Flammability (UL Rating) (1.50 mm)	V-0		UL 94
Flammability (UL Rating) (3.00 mm)	V-0		UL 94

Glow Wire Flammability Index (0.400 mm)	960	°C	IEC 60695-2-12
Glow Wire Flammability Index (0.750 mm)	960	°C	IEC 60695-2-12
Glow Wire Flammability Index (1.50 mm)	960	°C	IEC 60695-2-12
Glow Wire Flammability Index (3.00 mm)	960	°C	IEC 60695-2-12
Glow Wire Ignition Temperature (0.400 mm)	960	°C	IEC 60695-2-13
Glow Wire Ignition Temperature (0.750 mm)	960	°C	IEC 60695-2-13
Glow Wire Ignition Temperature (1.50 mm)	800	°C	IEC 60695-2-13
Glow Wire Ignition Temperature (3.00 mm)	775	°C	IEC 60695-2-13

[00072] Tables 2 and 3 list exemplary polyamide compositions of the invention (Table 2) as well as exemplary comparative examples (Table 3). Table 4 lists selected tested properties of the compositions of Table 2 and Table 5 lists selected tested properties of the comparative compositions of Table 3.

Table 2.

Additive	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7	Ex 8	Ex 9	Ex 10
A									90.4
B	81.4	80.9	81.4	91.4	91.6	91.4	92.4	92.4	
C	1.00	1.00	1.00	1.00	1.00	1.00			1.00
D									
E	0.1	0.1		0.1					
F			0.1		0.1	0.1	0.1	0.1	0.1
G									
H									
I	7.00	7.50	7.00	7.00	7.00	7.00	7.00	7.00	8.00
J	10.00	10.00	10.00						
K									
L	0.5	0.5	0.5	0.5	0.3	0.5	0.5	0.5	0.5

TOTAL (wt%)	100	100	100	100	100	100	100	100	100
Cu (ppm)					70	133	145	170	135
Br (ppm)					636	1080	1100	1300	1165

A= PA66, low viscosity; **B**= PA66, high viscosity; **C**= PA66, fine powder to assist compounding; **D**= aluminum stearate (lubricant); **E**= calcium stearate (lubricant); **F**= zinc stearate (lubricant); **G**= Acrawax® (lubricant); **H**= titanium dioxide (colorant); **I**= melamine cyanurate (non-halogen, nitrogen-containing flame retardant); **J**= Nylon 6 (PA6); **K**= phenolic organic heat stabilizer; **L**= copper heat stabilizer

Table 3.

Additive	Comp Ex 1	Comp Ex 2	Comp Ex 3	Comp Ex 4
A	90.2			
B		90.8	90.8	90.3
C	1.00	1.00	1.00	1.00
D	0.1			
E				
F		0.1	0.1	0.1
G	0.25			
H	0.1			
I	8.00	7.00	7.00	7.00
J				
K	0.4	0.5		0.5
L				
M			0.5	0.5
N		0.5	0.5	0.5
O		0.1	0.1	0.1
TOTAL (wt%)	100	100	100	100

A= PA66, low viscosity; **B**= PA66, high viscosity; **C**= PA66, fine powder to assist compounding; **D**= aluminum stearate (lubricant); **E**= calcium stearate (lubricant); **F**= zinc stearate (lubricant); **G**= Acrawax® (lubricant); **H**= titanium dioxide (colorant); **I**= melamine cyanurate (non-halogen, nitrogen-containing flame retardant); **J**= Nylon 6 (PA6); **K**= phenolic organic heat stabilizer; **L**=

copper heat stabilizer; M= hindered amine organic heat stabilizer; N=thioester organic heat stabilizer; O= phosphite organic heat stabilizer

Table 4.

Property	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7	Ex 8	Ex 9	Ex 10
UL94 (3mm)							V-0	V-2	V-0
UL94 (1.5mm)							V-0	V-2	V-0
UL94 (0.75mm)							V-0	V-2	V-0
UL94 (0.4mm)	V-0	V-0	V-0	V-0			V-0	V-2	V-0
Tensile Strength (MPa)	86.9	85.7	89	89.3	85.8	91.3	85	90	89.5
Tensile Modulus (MPa)								3279	3405
Elongation at Break (%)	4.2	4	7.4	4.2			3.9	6.9	5.1
Flexural Strength (MPa)								101	110
Flexural Modulus (MPa)								3296	3826
Notched Charpy (kJ/m ²)								2.7	
Notched Izod (kJ/m ²)									1.6
Density (g/cm ³)									1.16
GWIT (°C)									960

Table 5.

Property	Comp Ex 1	Comp Ex 2	Comp Ex 3	Comp Ex 4
UL94 (3mm)				
UL94 (1.5mm)				
UL94 (0.75mm)	V-0			
UL94 (0.4mm)	V-0	V-2	V-2	V-2
RV	53			
Tensile Strength (MPa)	88.4	90.6	90.4	92.6

Tensile Modulus (MPa)				
Elongation at Break (%)	4.4	6.8	8.3	8.2

[00073] Table 6 lists several commercial (conventional) polyamide compositions that were tested against an exemplary composition of the present invention (Example 1 in the table). Table 7 compares selected electrical properties of these compositions and Table 8 compares their elongation/impact properties.

Table 6.

	Trademark	Grade Code	Material Type / Feature
Example 1		ECO366	NHFR-PA66, unfilled, heat stabilized
Conventional 1	Vydyne	ECO366H	NHFR-PA66, unfilled, heat stabilized
Conventional 2	Schulamid	66 MV 5 FR	NHFR-PA66, unfilled
Conventional 3	Leona	FR370	NHFR-PA66, unfilled
Conventional 4	Leona	FR561	NHFR-PA66, unfilled
Conventional 5	Ultramid	A3U30	NHFR-PA66, unfilled
Conventional 6	Novamid	3010N-5-SL4-3X	NHFR-PA66, unfilled
Conventional 7	Zytel	FR15	NHFR-PA66, unfilled, high flow
Conventional 8	Zytel	FR7025V0F	NHFR-PA66, unfilled, FR(30)
Conventional 9	Zytel	FR7026V0F	NHFR-PA66, unfilled, heat stabilized, FR(30)
Conventional 10	Grilon	AS V0	NHFR-PA66, unfilled
Conventional 11	Kopa	KN3322V0	NHFR-PA66, unfilled
Conventional 12	Durethan	A30SFN31	NHFR-PA66, unfilled
Conventional 13	Latamid	66 H-V0	NHFR-PA66, unfilled
Conventional 14	Lumid	GN-1001BF	NHFR-PA66, unfilled
Conventional 15	Frianyl Frianyl	A2 V0 A63NV0	NHFR-PA66, unfilled, high flow
Conventional 16	Frianyl Frianyl	A3 V0 A63V0	NHFR-PA66, unfilled
Conventional 17	Frianyl Frianyl	A3 RV0 A63RV0	NHFR-PA66, unfilled, heat stabilized
Conventional 18	Radiflam	A FR	NHFR-PA66, unfilled
Conventional 19	Torzen Marathon	FRU4800 XHL	NHFR-PA66, unfilled, heat stabilized
Conventional 20	Technyl	A50H1	NHFR-PA66, unfilled, heat stabilized
Conventional 21	Amilan	CM3004-V0	NHFR-PA66, unfilled
Conventional 22	Vampamid	66 0024V0	NHFR-PA66, unfilled

Table 7.

	Thickness	RTI [Elec / Imp / Str]	Dielectric Strength (kV/mm)	Volume Resistivity (10 ^x Ω-cm)	Flame Class	GWIT (°C)
Example 1	0.20 mm		20	19	V-0	
	0.40 mm	[150 / 110 / 130]			V-0	960
	0.75 mm	[150 / 110 / 130]			V-0	960
	1.5 mm	[150 / 110 / 130]			V-0	800
	3.0 mm	[150 / 110 / 130]			V-0	775
Conventional 1	0.40 mm	[120 / 75 / 105]	17	10	V-0	960
	0.75 mm	[120 / 80 / 110]			V-0	960
	1.5 mm	[120 / 80 / 110]			V-0	700
	3.0 mm	[120 / 80 / 110]			V-0	700
Conventional 2	0.20 mm	[65 / 65 / 65]	16	11	HB	960
	0.40 mm	[65 / 65 / 65]			V-0	960
	0.75 mm	[65 / 65 / 65]			V-0	960
	1.5 mm	[65 / 65 / 65]			V-0	960
	3.0 mm	[65 / 65 / 65]			V-0	960
Conventional 3	0.38 mm	[95 / 65 / 95]	31	15	V-0	
	0.75 mm	[130 / 90 / 105]			V-0	
	1.5 mm	[130 / 105 / 105]			V-0	
	3.0 mm	[130 / 105 / 105]			V-0	
Conventional 4	0.75 mm	[130 / 90 / 105]			V-0	
	1.5 mm	[130 / 105 / 105]			V-0	
	3.0 mm	[130 / 105 / 105]			V-0	
Conventional 5	0.25 mm		25	13	V-0	
	0.40 mm				V-0	
	0.75 mm	[130 / 90 / 120]			V-0	
	1.5 mm	[130 / 90 / 120]			V-0	
	3.0 mm	[130 / 90 / 120]			V-0	
Conventional 6	0.40 mm		23	13	V-0	
	0.75 mm	[130 / 105 / 120]			V-0	
	1.5 mm	[130 / 105 / 120]			V-0	
	3.0 mm	[130 / 105 / 120]			V-0	
Conventional 7	0.75 mm	[130 / 75 / 85]	22	14	V-0	725
	1.5 mm	[130 / 75 / 85]			V-0	725
	3.0 mm	[130 / 75 / 85]			V-0	775
Conventional 8	0.40 mm		18	12	V-0	960
	0.75 mm	[130 / 75 / 85]			V-0	775
	1.5 mm	[130 / 75 / 85]			V-0	775
	3.0 mm	[130 / 75 / 85]			V-0	775

Conventional 9	0.40 mm 0.82 mm 1.5 mm 3.0 mm	[65 / 65 / 65] [130 / 95 / 110] [130 / 95 / 110] [130 / 95 / 110]	18	12	V-0 V-0 V-0 V-0	960 960 960 960
Conventional 10	0.75 mm 0.85 mm 1.5 mm 3.0 mm	[115 / 105 / 120] [115 / 105 / 120] [115 / 105 / 120] [115 / 105 / 120]			V-0 V-0 V-0 V-0	
Conventional 11	0.40 mm 0.75 mm 1.5 mm 3.0 mm	[105 / 105 / 120] [105 / 105 / 120] [105 / 105 / 120] [105 / 105 / 120]			V-0 V-0 V-0 V-0	960 960 960 750
Conventional 12	0.40 mm 0.75 mm 1.5 mm 3.0 mm	[130 / 105 / 125] [130 / 105 / 125] [130 / 105 / 125] [130 / 105 / 125]			V-0 V-0 V-0 V-0	775 775 775 775
Conventional 13	0.40 mm 0.81 mm 1.5 mm 3.0 mm	[125 / 75 / 75] [125 / 75 / 75] [125 / 80 / 85]	14	13	V-0 V-0 V-0 V-0	
Conventional 14	0.4 mm 0.75 mm	[65 / 65 / 65]			V-0	960 850
Conventional 15	0.40 mm	[65 / 65 / 65]			V-0	
Conventional 16	0.40 mm 0.75 mm 1.5 mm 3.0 mm	[125 / 90 / 115] [125 / 95 / 115] [125 / 95 / 120] [125 / 95 / 120]			V-0 V-0 V-0 V-0	
Conventional 17	0.25 mm 0.40 mm 0.75 mm 1.5 mm 3.0 mm	[65 / 65 / 65] [130 / 105 / 115] [130 / 105 / 120] [130 / 105 / 120] [130 / 105 / 120]	25	13	V-0 V-0 V-0 V-0 V-0	775 775 775
Conventional 18	0.40 mm 0.75 mm 1.5 mm 3.0 mm	[130 / 90 / 120] [130 / 100 / 120] [130 / 100 / 120] [130 / 100 / 120]			V-0 V-0 V-0 V-0	960 960 930 750
Conventional 19	0.25 mm 0.40 mm 0.71 mm 1.5 mm 3.0 mm	[130 / 95 / 125] [140 / 110 / 140] [140 / 110 / 140] [140 / 110 / 140]	21	12	V-0 V-0 V-0 V-0	960 960 960 725

Conventional 20	0.40 mm	[130 / 105 / 120]			V-0	960
	0.75 mm	[130 / 105 / 120]			V-0	960
	1.5 mm	[130 / 105 / 120]			V-0	775
	3.0 mm	[130 / 105 / 120]			V-0	700
Conventional 21	0.25 mm		28	13	V-0	
	0.40 mm				V-0	
	0.66 mm	[130 / 105 / 105]			V-0	
	1.5 mm	[130 / 105 / 105]			V-0	
Conventional 22	0.75 mm	[65 / 65 / 65]			V-0	
	1.5 mm	[65 / 65 / 65]			V-0	
	3.0 mm	[65 / 65 / 65]			V-0	

Table 8.

	Tensile Strength Yield / Break (MPa)	Tensile Elongation Yield / Break (%)	Tensile Modulus (MPa)	Flextural Modulus (MPa)	Notched Charpy Impact 23°C / -30°C (kJ/m ²)
Example 1	83 / -	- / 6		3900	3.4 / 3.7
Conventional 1	83 / -	- / 5		3900	3.4 / 3.7
Conventional 2	80 / -	4.9 / -	3600	3700	5 / 3
Conventional 3	83 / -	- / 7		3300	3 / -
Conventional 4					
Conventional 5	80 / -	- / 3	3700	3600	3 / -
Conventional 6	81 / -	4.2 / -	3100		4 / -
Conventional 7	85 / -	- / 10		3450	
Conventional 8	90 / 80	4 / 10	3800	3660	4 / 3
Conventional 9	89 / 80	4 / 10	3800		4 / 3
Conventional 10	90 / 80	4 / 9	3900		4 / -
Conventional 11	- / 86	- / 13		3400	4.5 / -
Conventional 12	85 / -	4.1 / -	3800	3700	10 / -
Conventional 13	75 / 70	3 / 8	4200	3300	3 / -
Conventional 14	79 / -	- / 30.0		3000	4.9 / -
Conventional 15	80 / -	- / 6.0	3500		3.5 / 3.0

Conventional 16	80 / -	- / 8.0	3500		3.5 / 3.0
Conventional 17	85 / -	- / 12.0	3400		3.5 / 3.0
Conventional 18	77 / -	- / 12.0	3450	3200	4.5 / 4
Conventional 19	- / 80	- / 13	3700		2.4 / -
Conventional 20	86 / 75	4.2 / 21.0	3800	3700	3.2 / -
Conventional 21	85 / -	- / 7.5		3500	4.5 / -
Conventional 22	70 / -	- / 15	3000		

[00074] As evidenced by the results of Tables 7 and 8, the polyamide compositions of the present invention when compared to the conventional art were observed to unexpectedly (i) exhibit best in class Electrical RTI values (150°C at all thicknesses) for an unfilled PA66 composition; (ii) retain excellent electrical properties, dielectric strength, volume resistivity, comparative tracking index, and high amp arc ignition in the presence of a copper-containing heat stabilizer; (iii) achieve a superior UL94 V0 rating down to a 0.2 mm thickness; (iv) provide high flow to allow the filling of thin-walled parts during injection molding and reduced cavity and injection pressures. In addition, it is highly desirable that a PA-6,6 composition is able to exhibit equivalent or superior electric performance at higher temperatures compared to more expensive conventional PA-4,6; PA-6,1 compositions, while maintaining the required mechanical (*e.g.*, elongation/break/impact) properties.

[00075] All publications and patents cited herein are incorporated by reference in their entireties.