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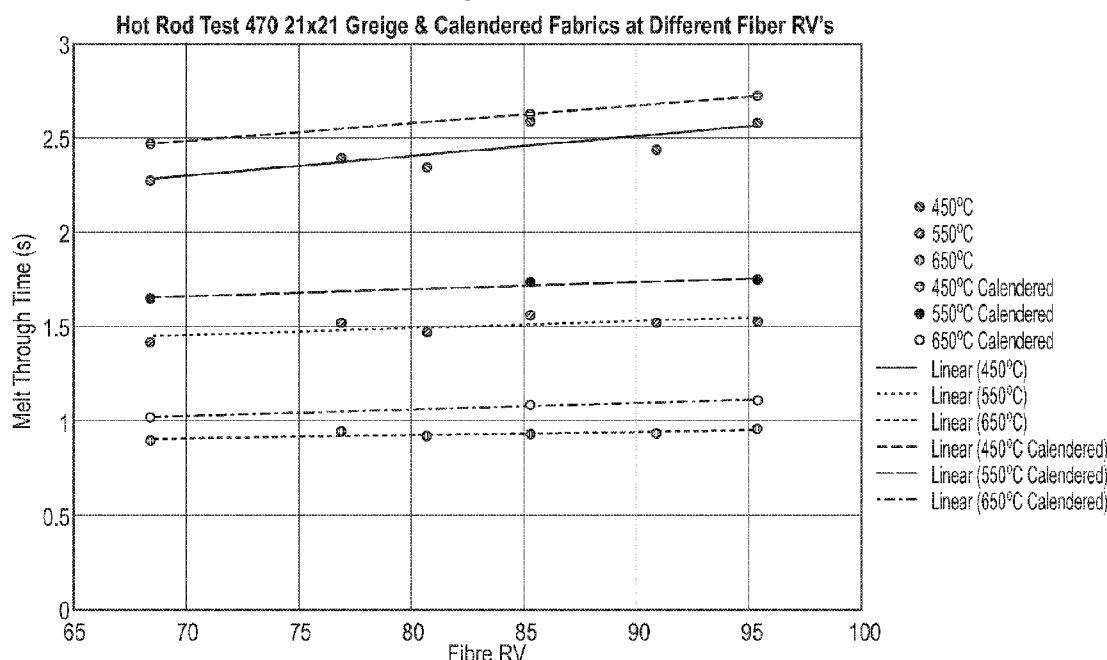
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FIG. 1



(57) Abstract: A method of making a woven fabric having improved melt-through resistance and/or thermal resistance constant, said method comprising the steps of (i) weaving a spun synthetic polyamide yarn and (ii) subjecting the resulting woven fabric to a High Temperature-High Pressure (HTHP) treatment, to provide a woven fabric having a bulk density of greater than 875 kg/m³ and a fiber relative viscosity (RV) density factor of at least 62,500. The invention further provides a woven fabric produced by said method and the use of the woven fabric to make an airbag having improved resistance to pinhole failure.

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AIRBAG FABRICS

Cross Reference to Related Application(s)

[0001] This application claims priority to GB Application No. 2017576.6 filed on November 6, 2020, the disclosure of which is hereby incorporated by reference in its entirety.

Field of the invention

[0002] The present invention relates to finished woven fabrics comprising spun synthetic polyamide yarn which are suitable as improved airbag fabrics, and a method of making said fabrics.

Background to the invention

[0003] Inflatable airbags are a key component of vehicle safety systems and are installed in virtually every vehicle produced globally. Typically, inflatable airbags are made from woven fabric of nylon or polyester yarns. To meet the requirements for effective inflation, airbag fabric must meet certain tensile strength requirements and have the ability to resist the passage of air, and it is therefore desirable for airbags to have a very low air permeability. As used herein, "airbag" means inflatable passive safety restraints for automobiles and many other forms of transportation, including aviation applications. In recent years, the number of airbags, and the area of coverage for these airbags within various types of vehicular cabins has increased. Multiple air bag configurations in use include airbags for the front seating area, for side impact protection, for rear seat use, for use in headliner area inflatable curtains, and for use in inflatable seat belts or pedestrian airbags. There is a continuing automotive trend towards smaller and lighter vehicles, meaning that less space is available for mandatory safety items such as airbags. It is an object of automobile manufacturers to improve crash impact safety systems in general, and particularly airbag modules, in terms of safety, environmental footprint and cost.

[0004] Reduction of airbag module weight per unit area of deployable airbag generally enables total weight reduction without safety compromise. This has become even more important as the number of airbags per vehicle has risen sharply to provide passenger protection at multiple angles. Airbag modules are therefore required to be more efficient in both size and weight.

[0005] Reduction of airbag inflator size also enables total weight reduction and increased cost savings. To ensure equal efficacy, the smaller inflators are hotter than historical counterparts.

[0006] The trend in the airbag module industry is towards thinner, lighter fabrics used with smaller, hotter inflators. However, this more aggressive design has resulted in experienced events where hot particles and/or hot gases from airbag deployment discharges have penetrated airbag fabrics, injuring vehicle passengers and resulting in the recall of millions of modules. Protection from hot particle penetration and release of hot gases, collectively referred to herein as fabric pinhole failures, becomes increasingly important as the number of airbags per vehicle and their relative proximity to the passenger increases in the effort to improve vehicle safety. Potential solutions to pinhole failures include selecting fabric materials with higher latent heat of melting, increasing fabric weights and applying coating chemistries but there remains a need for improved fabrics which are suitable for use in modern airbag modules.

[0007] It is an object of this invention to provide airbag fabrics which have a greater resistance to pinhole failure, in order to maintain gains in airbag module weight reduction and improved cost efficiency. Thus, it is a particular object of this invention to provide airbag fabrics which have a greater resistance to pinhole failure and which are also relatively thinner and lighter than conventional airbag fabrics, particularly without detriment to the air permeability or deterioration thereof to unacceptable levels.

Summary of the invention

[0008] According to a **first aspect** of the present invention, there is provided a method of making a woven fabric comprising the steps of (i) weaving a spun synthetic polyamide yarn and (ii) subjecting the resulting woven fabric to a High Temperature-High Pressure (HTHP) treatment, preferably wherein said HTHP treatment is calendering, to provide a woven fabric having a bulk density of greater than 875 kg/m^3 and a fiber relative viscosity (RV) density factor of at least 62,500.

[0009] According to a **second aspect** of the present invention, there is provided a woven fabric (preferably a calendered woven fabric) comprising spun synthetic polyamide yarn, wherein said fabric is made from polyamide yarn woven in the warp direction and weft direction, wherein the bulk density of the fabric is greater than 875 kg/m^3 , and wherein the fabric relative viscosity (RV) density factor is at least 55,000.

[00010] In this invention, relative viscosity (RV) of the polyamide is defined as the formic acid relative viscosity, which is measured at two stages during manufacture of the woven fabric. The first RV measurement is taken immediately after extrusion of a polyamide fiber from the spinneret, and before any application of spin finish and before drawing, and this measurement is referred to as the "fiber RV". The second RV measurement is taken from polyamide yarn in the finished fabric, and this measurement is referred to herein as the "fabric RV". The inventors have observed that the RV of the polyamide reduces significantly during manufacture of the fabric, primarily as a result of drawing the extruded fiber during the subsequent spinning process. The fabric RV is therefore significantly lower than the fiber RV.

[00011] Preferably, said woven fabric is made from polyamide yarns of a single polymer type and titer woven in both the warp direction and weft direction.

[00012] The woven fabric preferably exhibits an improved melt-through resistance, measured as defined herein which is at least 10% higher than that of uncalendered fabrics of the same fiber type and weight per unit of fabric area. The woven fabric preferably exhibits a melt-through resistance at 450°C of least 2.00 seconds as measured herein. The inventors have found that the melt-through resistance of a fabric is predictive of the likelihood of pinhole failures in a full airbag module deployment test. Melt-through resistance improves with fabric weight, where heavier weight fabrics provide higher melt-through resistance.

[00013] The inventors have also found that the thermal resistance constant (X) of the fabric, measured as defined herein, is particularly predictive of the likelihood of pinhole failures in a full airbag module deployment test. The woven fabric of the invention should exhibit a thermal resistance constant (X) at 450°C of at least 6.0, preferably at least 6.2, preferably at least 6.5, preferably at least 7.0, preferably no more than 10.0, preferably no more than 9.0, typically no more than 8.6 and typically no more than 8.0, and preferably in the range of from 6.0 to 10.0, preferably from 6.2 to 9.0, preferably from 6.5 to 8.6, preferably 6.5 to 8.0 °C.s.mm⁻¹. The woven fabric of the present invention should exhibit a thermal resistance constant (X) at 650°C of at least 3.3, preferably at least 3.5, preferably at least 3.8, preferably no more than 6.0, preferably no more than 5.5, preferably no more than 5.2 and typically no more than 5.0, and preferably in the range of from 3.3 to 6.0, preferably from 3.3 to 5.5, preferably from 3.5 to 5.2, preferably 3.8 to 5.0 °C.s.mm⁻¹.

[00014] The inventors have also found a surprising improvement in melt-through resistance and thermal resistance constant with increasing bulk density, where fabrics of higher density are

much more resistant to high temperature penetration than lower density fabrics of the same polymer, yarn titer and mass of fabric per unit area (g/m^2).

[00015] Moreover, the inventors have also found a substantial and apparently synergistic effect of increased polymer viscosity and bulk density to provide improved melt-through resistance and higher thermal resistance constant. As such, the inventors have found that the RV density factor, measured as defined herein, is predictive of the likelihood of pinhole failures in a full airbag module deployment test. An RV density factor is defined herein using each of the two measurements for relative viscosity, to provide a "fiber RV density factor" and a "fabric RV density factor".

[00016] The RV of the polyamide is related to the molecular weight distribution of the polymer. The inventors' finding is especially surprising as fabric melt-through resistance has not previously been reported to be related to RV, nor has RV been observed to affect polymer melting point of nylon fabrics.

[00017] Such fabrics show improved resistance to hot particulate penetration through the airbag during deployment in the new, more effective airbag module designs.

[00018] According to a **third aspect** of the present invention, there is provided an article, preferably an airbag, made from the woven fabric of the second aspect of the invention or made from the woven fabric produced by the process of the first aspect of the invention.

[00019] According to a **fourth aspect** of the present invention, there is provided the use of a woven fabric according to the second aspect or a woven fabric produced by the process of the first aspect to improve the resistance to pinhole failure of an airbag made therefrom.

[00020] According to a **fifth aspect** of the present invention, there is provided a method of making an airbag, or a method of improving the resistance to pinhole failure of an airbag, said method comprising the steps of (i) providing a woven fabric comprising spun synthetic polyamide yarn wherein said fabric is made from polyamide yarn woven in the warp direction and weft direction, (ii) subjecting said woven fabric to a High Temperature-High Pressure (HTHP) treatment, preferably wherein said HTHP treatment is calendering, such that the HTHP-treated woven fabric exhibits a bulk density of greater than 875 kg/m^3 and a fabric relative viscosity (RV) density factor of at least 55,000, and (iii) constructing the airbag from said HTHP-treated woven fabric.

[00021] According to a **sixth aspect** of the invention, there is provided a method of adjusting the melt-through resistance and/or thermal resistance constant of a woven fabric comprising spun synthetic polyamide yarn, said method comprising the steps of (i) weaving the fabric from

a spun synthetic polyamide yarn and (ii) subjecting the resulting woven fabric to a High Temperature-High Pressure (HTHP) treatment, preferably wherein said HTHP treatment is calendering, to provide a woven fabric having a bulk density of greater than 875 kg/m³ and a fiber relative viscosity (RV) density factor of at least 62,500.

5 **Detailed description of the invention**

[00022] The woven fabrics of the present invention are composed of high tenacity spun synthetic polyamide yarns. The yarns are made from fibers which are in the form of continuous filaments. Such filaments are formed by extrusion of molten polymer through spinnerets at high temperatures and pressures, and subsequently quenched in air, coated with spin finish
10 lubricant, drawn between pairs of godets, lightly textured to provide enough entanglement to make a coherent yarn, and then wound up on cardboard tubes, as bobbins.

[00023] The spin finish on the filaments facilitates the processing of yarn during its production and may be subsequently removed to provide the finished woven fabric, depending on the requirements of subsequent processing. Removal of the spin finish may be effected prior
15 to, during or after weaving (preferably during or after weaving), according to conventional techniques well-known in the art.

[00024] In the woven fabrics of the present invention, at least a majority (and preferably all) of the yarn used in the warp direction of fabric is preferably formed from synthetic fiber made from a single polyamide composition. Similarly, at least a majority (and preferably all) of the yarn
20 used in the weft direction of fabric is preferably formed from synthetic fiber made from a single polyamide composition. In a preferred but non-limiting embodiment, at least a majority (and preferably all) of the yarn used in the warp direction and weft direction of fabric is formed from synthetic fiber formed from a single polyamide composition. Preferably a single polyamide is used in each of the warp and weft directions and preferably the same polyamide is used in both
25 the warp and weft directions.

[00025] Suitable polyamide fibers are preferably selected from those formed from nylon 6,6, nylon 6, nylon 6,12, nylon 7, nylon 12, nylon 4,6 or copolymers or blends thereof. In a preferred but non-limiting embodiment, the polyamide is nylon 6,6.

[00026] The fiber RV in this invention is at least 66, preferably at least 68, preferably at least 70, preferably at least 75, preferably at least 78, preferably at least 80, preferably at least 85,
30 preferably at least 90, and typically no more than 150, typically no more than 110, typically no more than 100, typically no more than 95. Preferably, the fiber RV is in the range of from 68 to 150, preferably from 70 to 110, preferably from 75 to 110, preferably from 78 to 110, preferably

from 80 to 100, preferably from 85 to 100, preferably from 85 to 95. The inventors observed no evident relationship between melt-through resistance and the melting point of the polyamide in either the base yarn or the fabric. Thus, the positive correlation observed by the inventors between melt-through resistance and relative viscosity is surprising given that the melting point of the higher-RV polyamide yarn is effectively indistinguishable from the melting point of a corresponding lower-RV polyamide yarn over the relevant relative viscosity range.

[00027] Polyamide yarns which exhibit such relative viscosity values for the fiber RV may be prepared by means conventional in the art. For instance, relative viscosity may be increased by increasing the degree of polymerization, i.e. the molecular weight, of the polyamide as is known in the art. For instance, the molecular weight and relative viscosity may be increased by a solid state polymerization step, typically conducted under dry nitrogen at elevated temperature (for instance about 180°C).

[00028] In the woven fabrics of the present invention, at least a majority (and preferably all) of the yarn in the warp direction is yarn having a tenacity from 6.8 to 10.1 g/den. Similarly, at least a majority (and preferably all) of the yarn in the weft direction is yarn having a tenacity from 6.8 to 10.1 g/den. In a preferred but non-limiting embodiment, at least a majority (and preferably all) of the yarn in the warp and weft directions is yarn having a tenacity from 6.8 to 10.1 g/den.

[00029] The yarn used in the present invention preferably has a linear mass density in the range from about 100 to about 2000 decitex, preferably from about 150 to about 1000 decitex, preferably from about 150 to about 940 decitex, preferably from about 150 to about 750 decitex, preferably from about 400 to about 750 decitex.

[00030] The linear mass density of fiber which constitutes the yarn is preferably in the range from about 1 to about 25 decitex per filament (DPF), or from about 2 to about 12 decitex per filament (DPF).

[00031] The woven fabric of the present invention is preferably made from yarn having from 90 to 300 ends/dm, preferably from 160 to 240 ends/dm, preferably at least 180 ends/dm, preferably at least 190 ends/dm, and preferably from 180 to 220 ends/dm. Preferably, the woven fabric exhibits a symmetrical construction. Thus, the ends/dm of the warp yarn is preferably the same as the ends/dm of the weft yarn.

[00032] The woven fabric of the present invention may be formed from warp and weft yarns using weaving techniques known in the art. Suitable weaving techniques include, but are not limited to a plain weave, twill weave, satin weave, modified weaves of these types, one piece woven (OPW) weave, or a multi-axial weave. Suitable looms that can be used for weaving

include a waterjet loom, airjet loom or rapier loom, and preferably the loom is a waterjet loom. These looms can also be used in conjunction with a jacquard in order to create an OPW structure. The fabrics may be finished according to any methods known in the art, including drying on loom, scouring, can drying and heat setting. Preferably, the woven fabric of the present invention is a waterjet woven fabric which is dried on loom, or dried by a separate process. In waterjet weaving, the dissolution of spin finish in water, and the rubbing of yarns against one another and the heddles and reed of the loom, causes removal of the spin finish lubricant from the yarn.

[00033] The woven fabric of the present invention is manufactured by subjecting a woven fabric to elevated temperature and pressure (referred to herein as High Temperature-High Pressure (HTHP) treatment).

[00034] The HTHP treatment step has been disclosed in WO-2017/079499-A and WO-2018/204154-A, the disclosure of which HTHP treatment step is incorporated herein by reference. In these methods, a woven fabric having a top surface and a bottom surface is treated in order to permanently modify the cross-section and fuse at least a portion of the fibers in the yarn on the top surface or at least a portion of the fibers in the yarn on the bottom surface, and preferably at least a portion of the fibers in the yarn on each of the top and bottom surfaces. In a preferred embodiment, the woven fabric is treated in order to permanently modify the cross-section and fuse at least a majority of the fibers in the yarn on the top surface or at least a majority of the fibers in the yarn on the bottom surface, and preferably a majority of the fibers in the yarn on each of the top and bottom surfaces.

[00035] The HTHP treatment of the woven fabric is effected at a temperature sufficient to permanently modify the cross-section and fuse at least a portion of the fibers in the yarn. In one embodiment, the temperature used is above the softening temperature of the yarn. Preferably, HTHP treatment is conducted at temperatures in the range of from about 130°C to about 240°C, preferably in the range of from about 220°C to about 240°C. In particular, fabrics formed from nylon 6,6 yarn are suitably HTHP-treated at temperatures in the range of from about 220°C to about 240°C. Preferably, the fabrics are HTHP-treated at high pressures in the range of from about 28MPa to about 115MPa, preferably in the range of from about 35 to about 70 MPa, preferably in the range of from about 50 to about 65 MPa, typically at about 57 MPa. The pressure is calculated from the total applied force on the area of fabric at the calender nip point. Preferably, the fabrics are HTHP-treated at a line speed in the range of from about 5 to about 80 m/min, preferably from about 5 to about 70 m/min, preferably from about 5 to about 50

m/min, and preferably at least 10 m/min. HTHP treatment may be effected by any method known in the art to apply temperatures and pressures to a woven fabric, and suitable to permanently modify the cross-section and fuse at least a portion of the fibers in the yarn. In a preferred embodiment, the HTHP treatment is or comprises a calendering step, preferably hot-roll calendering.

[00036] In a preferred embodiment, the HTHP treatment is conducted in the presence of a heat transfer fluid, for instance as taught in WO-2018/204154-A, the disclosure of which process is incorporated herein by reference. The heat transfer fluid may be a liquid or a vapour, which may be added during the HTHP treatment step or in added in a prior step of the fabric production process and retained by the yarn. In one non-limiting embodiment, the presence of a heat transfer fluid results from the carry-over of residual moisture introduced by weaving with a water jet loom, or from a washing or scouring process, or from a dyeing process. Preferably, the heat transfer fluid is or comprises water, or is predominantly water. Where the heat transfer fluid is a vapour, it may be or predominantly be or comprise steam. The heat transfer fluid may be applied by a bath, or by a foulard liquid application system or by a liquid spray system or by a vapor phase application system. The heat transfer fluid should be inert or benign so as not to damage the fabric, and may be any liquid or vapor fitting that description. Preferably, the heat transfer fluid is present in an amount of from 5 to 30, preferably from 10 to 20, preferably from 12 to 18 wt%, based on the weight of the dry fabric. The use of a heat transfer fluid allows a reduction in the temperature and/or pressure (particularly temperature) used in the HTHP process, relative to a process in which a heat-transfer fluid is not used. Thus, in this embodiment the HTHP treatment may be conducted at a temperature in the range of 100 to 240°C, preferably in the range of 150 to 190°C, and a pressure in the range of from 28 to 115 MPa, preferably in the range of from 35 to 70 MPa, preferably in the range of from about 50 to about 65 MPa. In one embodiment the temperature is below the dry softening temperature of the yarn. Alternatively, the use of a heat transfer fluid allows an increase in the production speed of the HTHP treatment, relative to a process in which a heat-transfer fluid is not used, without detriment to the reduction in the permeability of the resultant fabric.

[00037] The term "permanently modified cross-section", as used herein and as illustrated in WO-2017/079499-A (the disclosures of which illustrations are incorporated herein by reference), refers to a fiber cross-section that is a modified or compressed version of the cross-section of the majority of the fiber present in the fabric. The fiber may have any cross-section known in the art, including but not limited to circular, multi-lobal, tri-lobal, hexalobal or rectangular. In a preferred but non-limiting embodiment, the fiber has a circular cross-section (i.e. prior to HTHP-

treatment). In a preferred but non-limiting embodiment, the permanently modified cross-section results in at least a portion of the fiber being substantially flat.

[00038] Thus, a portion of the fibers in the treated fabric suitably exhibit an aspect ratio of from about 1.2:1 to about 10:1. As used herein, an aspect ratio of 1:1 describes a fiber cross section with a common radius from its centre to its outer surface; i.e. a fiber with a circular cross section has an aspect ratio of 1:1. In the HTHP-treated woven fabrics of the present invention, fibers on the surface of the woven fabric exhibit have a flattened cross section in at least 1 dimension and so have an aspect ratio of at least 1.2:1.

[00039] The term "permanent" or "permanently", as used herein, means that the modified cross-section does not revert to its original shape, as exemplified by the age testing in WO-2017/079499-A (the disclosures of which age-testing are incorporated herein by reference).

[00040] The woven fabric resulting from the HTHP treatment exhibits fibers which have a permanently modified cross-section and which are fused together so that air permeability and porosity of the fabric is reduced when compared to woven fabrics formed from the same synthetic fibers without such HTHP treatment, while maintaining good packing performance, high tensile strength of the fabric, low fabric weight and low cost.

[00041] The HTHP treatment (preferably) calendering increases the specific fabric density but does not measurably increase RV. Nor does it change the observed melt point of the woven fabric. Surprisingly, however, calendering is observed to improve the melt-through resistance of the fabric. Thus, the present invention provides a woven fabric which exhibits desirably low air permeability and high resistance to pinhole failures for a desirably low fabric weight by the application of a calendering process to a woven fabric comprising high RV yarn.

[00042] The calendered woven fabrics of the present invention exhibit improved melt-through resistance and are characterized by a combination of features.

[00043] In particular, the woven fabric exhibits a bulk density of at least 875 kg/m³, preferably at least 900 kg/m³, preferably at least 925 kg/m³, preferably at least 950 kg/m³, preferably at least 975 kg/m³. Preferably, the density is no more than 1200 kg/m³, preferably no more than 1100 kg/m³, typically no more than 1000 kg/m³. It will be appreciated that the bulk density as used herein refers to the bulk density in the HTHP-treated (preferably calendered) woven fabric.

[00044] The fiber RV density factor of the woven fabrics as defined herein is at least 62,500, preferably at least 63,000, more preferably at least 65,000, preferably at least 67,000, preferably at least 70,000, preferably at least 75,000, preferably at least 80,000, preferably at

least 85,000, and preferably not more than 100,000, preferably not more than 95,000, preferably not more than 92,000, and preferably in the range of 63,000 to 100,000, more preferably 65,000 to 95,000 and more preferably 67,000 to 92,000.

[00045] The RV of the polyamide in the woven fabric (referred to herein as the “fabric RV”) of the present invention, i.e. the HTHP-treated woven fabric, is preferably at least 60, preferably at least 65, preferably at least 70, preferably at least 75, preferably at least 78, preferably at least 80, preferably at least 85, preferably at least 90, and typically no more than 150, typically no more than 110, typically no more than 100. Preferably, the fabric RV is in the range of from 75 to 110, preferably from 78 to 110, preferably from 85 to 100.

[00046] The fabric RV density factor of the woven fabrics as defined herein is preferably at least 55,000, preferably at least 58,000, preferably at least 60,000, preferably at least 65,000, preferably at least 70,000, preferably at least 75,000, preferably at least 80,000, preferably no more than 95,000, preferably no more than 90,000, and preferably no more than 88,000, and preferably in the range of 55,000 to 95,000, preferably from 58,000 to 90,000, preferably from 60,000 to 88,000.

[00047] The woven fabrics of the present invention preferably exhibit a total fabric weight of from 50 to 500 g/m², preferably no more than 300 g/m², preferably no more than 260 g/m², preferably no more than 225 g/m², and preferably at least about 80 g/m², preferably at least about 100 g/m², preferably at least about 150 g/m², and typically at least 170 g/m². In a preferred embodiment, the woven fabrics of the present invention exhibit a total fabric weight of from 150 to 260 g/m², preferably from 170 to 260 g/m², preferably from 170 to 235 g/m², preferably from 190 to 220 g/m².

[00048] The thickness of the woven fabric of the present invention is preferably no more than 0.28, preferably no more than 0.25 mm, preferably no more than 0.24 mm, preferably no more than 0.23 mm, preferably no more than 0.22 mm, and typically at least 0.18 mm, more typically at least 0.19 mm, and more typically at least 0.20 mm.

[00049] The melt-through resistance of the woven fabrics of the present invention, measured at 450°C as described herein, is preferably at least 2.00 seconds, preferably at least 2.10 seconds, preferably at least 2.20 seconds, preferably at least 2.30 seconds, preferably at least 2.40 seconds, preferably at least 2.50 seconds, preferably at least 2.60 seconds, preferably at least 2.70 seconds. The inventors have observed that melt-through resistance increases with increasing fabric weight, and also varies as a function of fabric thickness.

[00050] The woven fabric of the present invention preferably exhibits a static air permeability (SAP) of no more than 6.0, preferably no more than 5.0, preferably no more than 4.0, preferably no more than 3.0, preferably no more than 2.0, preferably no more than 1.0, preferably no more than 0.5, preferably no more than 0.3, preferably no more than 0.2 l/dm²/min. The SAP referred to herein is the SAP of the fabric in its unaged state.

[00051] The woven fabric of the present invention preferably exhibits a dynamic air permeability (DAP) of no more than 700, preferably no more than 600, preferably no more than 500, preferably no more than 400, preferably no more than 300, preferably no more than 200, preferably no more than 150, preferably no more than 100 mm/s. The DAP referred to herein is the DAP of the fabric in its unaged state.

[00052] Preferably, the tear strength of the fabric in both the warp and weft directions is at least 120 N, preferably at least 150 N, preferably at least 170 N when the fabric is unaged.

[00053] The woven fabric exhibits elevated tensile strength in each and preferably both of the warp and weft directions, preferably at least 1000N, preferably at least 1500N, preferably at least 2000N, preferably at least 2500N, preferably at least 3000N.

[00054] To advance the objectives of weight and material cost reduction, and to minimize environmental impact via polymer recycling simultaneously, woven fabrics of the present invention are preferably uncoated. Fabrics comprising layers or coatings to reduce air permeability are commonly employed in airbags. Such prior art woven fabrics containing additional layers or coatings are referred to herein as “coated woven fabrics”, and take the form of any coating, web, net, laminate or film, which may have been used, for instance, to impart a reduction in air permeability or improvement in thermal resistance. Examples of such coatings include polychloroprene, silicone based coatings, polydimethylsiloxane, polyurethane and rubber compositions. Examples of such webs, nets and films include polyurethane, polyacrylate, polyamide, polyester, polyolefins, polyolefin elastomers and blends and copolymers thereof. It will be appreciated that the preferred uncoated woven fabrics of the present invention are not “coated woven fabrics” as defined herein.

[00055] In a particularly preferred embodiment, the woven fabric of the present invention is a woven fabric (preferably a calendered woven fabric) comprising spun synthetic polyamide yarn, wherein said fabric is made from polyamide yarn woven in the warp direction and weft direction (preferably wherein the fabric RV is at least 70, preferably at least 75 and otherwise as defined hereinabove), wherein the bulk density of the fabric is greater than about 900 kg/m³ (preferably at least 925 kg/m³, preferably at least 950 kg/m³ and otherwise as defined herein), and wherein

the fabric RV density factor is at least 55,000 (preferably at least 60,000 and otherwise as defined herein), wherein the woven fabric exhibits a thermal resistance constant (X) at 450°C in the range of from 6.0 to 10.0, preferably from 6.2 to 9.0, preferably from 6.5 to 8.6, preferably 6.5 to 8.0 °C.s.mm⁻¹, and a thermal resistance constant (X) at 650°C in the range of from 3.3 to 6.0, preferably from 3.3 to 5.5, preferably from 3.5 to 5.2, preferably from 3.8 to 5.0°C.s.mm⁻¹. In this embodiment, said yarn is suitably woven in the warp and weft direction to form a top surface of the woven fabric and a bottom surface of the woven fabric, wherein at least a portion of the yarn on the top surface and/or at least a portion of the yarn on the bottom surface have fibers that are fused together, and particularly wherein said fibers that are fused together have a permanently modified cross-section.

[00056] The present invention further provides an article made from the woven fabric described herein, or made from the woven fabric produced by the process described herein, wherein the article is selected from an airbag, sailcloth, inflatable slides, temporary shelters, tents, ducts, coverings and printed media, and particularly wherein the article is an airbag. The term "airbags", as used herein, includes airbag cushions. Airbag cushions are typically formed from multiple panels of fabrics and can be rapidly inflated. Fabric of the present invention can be used in airbags sewn from multiple pieces of fabric or from a one piece woven (OPW) fabric. One Piece Woven (OPW) fabric can be made from any method known to those skilled in the art.

[00057] It will be appreciated that the preferences and elements and steps described hereinabove are equally applicable to the first, second, third, fourth, fifth and sixth aspects.

[00058] The following test methods were used to characterize the woven fabrics.

[00059] (i) Formic Acid Relative Viscosity

The relative viscosity (RV) was measured on the fiber sample (collected immediately after fiber extrusion from the spinneret) according to ASTM D789-19 using a 90% formic acid solution.

Relative viscosity was also measured on a 20 gram sample of the finished woven fabric, i.e. after removal of any residual spin finish. Preferably, the fabric sample is treated prior to RV measurement in order to remove any remaining fiber lubricant oil, also known as spin finish. To remove the lubricant, each piece of fabric is soaked in enough methylene chloride to fully cover the sample. The sample is allowed to soak in a covered extraction funnel for twenty minutes with stirring. This procedure is then repeated. Once the second methylene chloride rinse is complete, the fabric is soaked in enough 1:1 methanol:methylene chloride to fully cover the sample. The sample is allowed to soak in a covered extraction funnel for twenty minutes with stirring. This procedure is repeated twice more. Once all five soak steps are complete,

remaining solvent is blown out of the fabric sample with clean pressurized air. The fabric is then allowed to air dry completely in an exhaust hood. Once dry, ASTM D789-19 is followed to measure the relative viscosity of the fabric sample.

[00060] (ii) Melt-through resistance (MTR)

- 5 To measure the melt-through resistance of the woven fabric, a “hot rod” test was used. Each fabric piece is 75 mm wide (warp direction) and 100 cm long (weft direction). Three fabric pieces are required per fabric sample (one per test temperature). Prior to testing, the fabric pieces are conditioned in a controlled atmosphere ($20 \pm 2^\circ\text{C}$ and $65 \pm 4\%$ RH) for at least 24 hours before testing. This test uses a 12L14 carbon steel cylindrical rod, which is 50 mm in length, 11 mm in diameter and each end being rounded at its edges with a 2mm radius giving a flat end which is 7mm in diameter, and weighing 36.5 g, with a specific heat capacity of $502.4\text{J}/(\text{kg}^\circ\text{K})$. The rod is heated to a controlled temperature in a muffle furnace for at least one hour to ensure temperature stabilization before testing. The hot rod is transferred to a delivery tube and brought into contact with a fabric piece which is mounted horizontally below the delivery tube.
- 10 The fabric pieces are tested using hot rods heated in the muffle furnace at muffle furnace set temperatures of at 450°C , 550°C and 650°C . The first test site must be at least 20 cm from the fabric selvage. A light-sensor in the delivery tube and a piezo-electric sensor attached to the catch tray positioned underneath the fabric allow a precise measurement of the time required for the rod to penetrate through the fabric once contact is made. The recorded time in the test is the total time (seconds) between the rod breaking the light beam and hitting the catch tray, wherein the total time equals the residence time of the rod on the fabric plus 0.19 seconds (which is the free-fall time it takes for the rod to pass between the light beam and the catch tray with no fabric present). The time required for the rod to melt through the fabric (i.e. the residence time of the rod on the fabric) is then calculated and this time period is defined as the melt-through resistance. Longer melt-through times indicate increased thermal resistance.
- 25 Each test is repeated 10 times at each temperature to characterize the time required to melt through the fabric sample in seconds.

[00061] (iii) Thermal Resistance Constant (X)

- The thermal resistance constant is calculated from the melt-through resistance according to the formula:

$$\text{thermal resistance constant (X)} = (T \times t) / (600 \times D)$$

where T is the temperature ($^\circ\text{C}$) of the MTR test; t is the MTR (seconds) measured as described herein; and D is the thickness (mm) of the fabric.

[00062] (iv) Fabric Count

Fabric count was assessed using ISO-7211-2.

[00063] (v) Fabric Thickness

Thickness testing is conducted on fabric specimens which have been conditioned to standard laboratory conditions of $20\pm 2^{\circ}\text{C}$ & $65\pm 4\%$ RH for at least 24hrs. The specimens are cut from the fabric in such a way that no two specimens possess any common warp or weft yarns.

Specimens are not cut within 20cm of either selvedge or at any creased, obviously damaged or dirty fabric regions. Specimens are suitably cut using a cutter die with a hydraulic press. The thickness of five specimens is measured with an electronic micrometer of testing range 0-25mm by 0.001mm (with 6.5mm diameter jaw faces) and the result recorded. The reported result (in units of mm) is the mean average of five individual specimen results.

[00064] (vi) Fabric Weight

Fabric weight was measured according to ISO 3801 (1977) with EASC amendments, and in accordance with EASC instruction 99040180 covering fabric testing (sections 3.05 & 4.01).

Weight testing is conducted on samples of fabric which have been conditioned to standard laboratory conditions of $20\pm 2^{\circ}\text{C}$ & $65\pm 4\%$ RH for at least 24hrs. Five square specimens of size 10x10cm are cut (each orientated on the bias at 45° to the warp direction) from the sample in a diagonal line pattern across the fabric in such a way that no two specimens possess any common warp or weft yarns. Specimens are not cut within 10cm of either selvedge or at any creased, obviously damaged or dirty fabric regions. Specimens are cut using a 10x10cm cutter die with a hydraulic press. Once cut, the five specimens are weighed in a 3 decimal place balance in units of grams & the result recorded. Each result is multiplied by 100 to give the fabric weight in g/m^2 . The reported fabric weight result is the mean average of five results.

[00065] (vii) Bulk density

The bulk density of the fabric is calculated by dividing the fabric weight per unit area (g/m^2) by the fabric thickness measurement (mm) with a conversion to units of kg/m^3 .

[00066] (viii) Static Air Permeability (SAP)

Static Air Permeability SAP was measured according to ISO 9237 but with the following amendments:

- (a) The test area is 100cm^2 .
- (b) The test pressure (partial vacuum) is 500 Pa.
- (c) Each individual test value is corrected for edge leakage.

(d) Static Air Permeability testing is conducted at six sites on a test fabric in a sampling pattern across and along the fabric in order to test 6 separate areas of warp and weft threadlines within the fabric.

(e) The reported Static Air Permeability (in units of l/dm²/min) is the mean average of the six measurements

[00067] (ix) Dynamic Air Permeability (DAP)

Dynamic Air Permeability is defined as the average velocity (mm/s) of air or gas in the selected test pressure range of 30-70kPa, converted to a pressure of 100kPa (14.2 psi) and a temperature of 20°C. Dynamic Air Permeability is measured according to test standard ASTM D6476 but with the following amendments:

- (a) The limits of the measured pressure range (as set on the test instrument) are 30-70kPa
- (b) The start pressure (as set on the test instrument) is adjusted to achieve a peak pressure of 100±5kPa.
- (c) The test head volume is 400cm³ unless the specified start pressure cannot be achieved with this head, in which case an interchangeable test head of volume 100, 200, 800 or 1600cm³ is used, as appropriate for the fabric under test.
- (d) Dynamic Air Permeability testing is conducted at six sites on a test fabric in a sampling pattern across and along the fabric in order to test 6 separate areas of warp and weft threadlines within the fabric.
- (e) The reported Dynamic Air Permeability (in units of mm/second) is the mean average of the six measurements.

[00068] (x) Fabric tensile testing

The tensile properties of the woven fabric, to determine maximum force (N) and elongation at maximum force (%), is measured according to standard ISO 13934-1 but with the amendments as listed below:

- (a) The initial gauge (clamp) length set on the Instron tensile tester is 200mm
- (b) The Instron crosshead speed is set at 200mm/min
- (c) Fabric specimens are cut initially to size 350x60mm but are then frayed down by unravelling the long edge threadlines to a testing width of 50mm.
- (d) Tensile testing is conducted on 5 warp direction and 5 weft direction specimens cut from each test fabric in a diagonal cross pattern and avoiding any areas within 200mm of the fabric selvages.

- (e) The maximum force (also known as breaking force or breaking load) is reported as the mean average of the maximum force results of the five warp direction specimens and the five weft direction specimens, in Newtons (N).
- (f) The elongation at maximum force (also known as percentage elongation or percentage extension) is reported as the mean average of the elongation at maximum force results of the five warp direction specimens and (separately) of the five weft direction specimens, as a percentage

[00069] (xi) Tear force

The tear force (also known as tear strength) of the fabric, expressed in Newtons (N), is determined according to standard ISO 13937-2 with the amendments as listed below:

- (a) The fabric specimen size is 150mm x 200mm (with a 100mm slit extending from the midpoint of the narrow end to the center).
- (b) Tear testing is conducted on 5 warp direction & 5 weft direction specimens cut from each test fabric in a diagonal cross pattern and avoiding any areas within 200mm of the fabric selvages.
- (c) Warp direction tear results are obtained from tested specimens where the tear is made across the warp (i.e. warp threadlines are torn) whilst weft direction results are obtained from tested specimens where the tear is made across the weft (i.e. weft threadlines are torn).
- (d) Each leg of the specimens is folded in half to be secured in the Instron clamp grips according to ISO 13937-2 annex D/D.2
- (e) Evaluation of test results is according to ISO 13937-2 section 10.2 "Calculation using electronic devices".
- (f) The warp tear force is reported as the mean average of the tear force results of the five warp direction specimens, whilst the weft tear force is reported as the mean average of the tear force results of the five weft direction specimens, in Newtons (N).

[00070] (xii) RV Density Factor

An RV density factor of the fabric is calculated by multiplying the relevant measurement of the formic acid relative viscosity (RV) with the bulk density (kg/m^3), to provide a "fiber RV density factor" and a "fabric RV density factor".

[00071] The present invention is further illustrated by the following examples. It will be appreciated that the examples are for illustrative purposes only and are not intended to limit the

invention as described above. Modification of detail may be made thereto without departing from the scope of the invention.

Examples

5

Example 1

[00072] A series of rapier-woven fabrics was manufactured with a construction of 210 x 210 ends/dm, each using nylon 6,6 yarn (linear mass density of 470dtex, tenacity of 81cN/tex, 136 filament, 3 DPF) of differing relative viscosities. In each fabric, the warp yarn was the same as the weft yarn. Fabrics 10, 40 and 20 were prepared using a calendering process with a nip force of 300N/mm, temperature of 168°C, 15 m/min speed, pressure of 43 MPa and 15% water by weight on both sides of the fabric. Melt-through resistance and thermal resistance constant of each fabric was tested at 450°C, 550°C and 650°C, and the results are presented in Table 1 and Figure 1 (MTR) for the calendered and non calendered fabrics at various fiber RV levels. Static and dynamic air permeability testing was also conducted. In Table 1 the non-calendered fabrics are designated by an ID of 1 to 6 and the calendered fabrics of the present invention are designated by an ID of 10, 20 and 40.

[00073] For each test temperature, the melt through resistance increased with increasing RV of the polyamide. Furthermore, the application of the calendering process further increased the melt through time of the fabric. The inventors observed that the calendering process significantly increased the density and RV density factor of the fabric (Table 1). Non calendered fabrics had a density <700 kg/m³, while the calendered fabrics had a density of >960 kg/m³. The results demonstrate that increased melt through resistance is correlated with increased fiber RV, increased density and increased RV density factor of the calendered fabric. In Table 1, "Cal." denotes whether the fabric was calendered, and "t (mm)" denotes thickness.

25

Table 1

ID	RV	Cal	t (mm)	Weight (g/m ²)	Density (kg/m ³)	Fiber density factor	Melt-through resistance constant			SAP (l/dm ² /min)	DAP (mm/s)
							450°C	550°C	650°C		
1	68.4	No	0.34	221.8	652	44621	2.3; 5.0	1.4; 3.8	0.9; 2.9	2.84	461
6	76.9	No	0.32	221.6	693	53253	2.4; 5.6	1.5; 4.4	0.9; 3.2	2.73	445
5	80.7	No	0.32	221	691	55734	2.3; 5.5	1.5; 4.2	0.9; 3.1	2.81	461
4	85.3	No	0.32	219.8	687	58590	2.6; 6.0	1.6; 4.5	0.9; 3.1	2.77	456
3	90.9	No	0.34	219	644	58550	2.4; 5.4	1.5; 4.1	0.9; 3.0	3.20	491
2	95.4	No	0.34	221.6	652	62178	2.6; 5.7	1.5; 4.1	1.0; 3.1	2.86	460
10	68.4	Yes	0.24	234	975	66690	2.5; 7.7	1.7; 6.3	1.0; 4.6	0.12	73
40	85.3	Yes	0.24	233.2	972	82883	2.6; 8.2	1.7; 6.6	1.1; 4.9	0.13	83
20	95.4	Yes	0.24	231.4	964	91982	2.7; 8.6	1.8; 6.7	1.1; 5.0	0.14	87

Example 2

[00074] A series of rapier-woven fabrics (scoured, 220x190 construction) was manufactured with nylon 6,6 yarn (470 dtex, 136 filaments, 81cN/tex and an RV of 72) and subjected to varying calendering conditions. A control sample (Item #1) was not subject to the calendering process.

5 Item #2 was subjected to a preferred calendering process in which both sides of the fabric were processed under a force of 400N/mm width, 57MPa pressure, 225°C and a roll speed of 5m/min. Item #3 was subjected to an alternative calendering process in which both sides of the fabric were processed under a force of 189N/mm width, 27 MPa pressure, 182°C and a roll speed of 23 m/min. The melt-through resistance and thermal resistance constant were measured as

10 described herein and the results presented in Table 2 and Figure 2 (MTR).

[00075] The results demonstrate that differing calendering conditions have an effect on melt-through resistance, thermal resistance constant, RV density factor and density for a given RV. The woven fabric of item #2 manufactured according to the preferred calendering process of the present invention exhibited the best melt-through resistance, the highest thermal

15 resistance constant, the highest RV density factor and the highest fabric density (945 kg/m³), and had superior melt-through resistance and thermal resistance constant to the non-calendered fabric of item #1 (density 666 kg/m³) and the calendered fabric of item #2 (density 745 kg/m³) which was prepared using alternative calendering conditions (lower temperature and pressure compared to item #2). Both calendered examples of items #2 and #3 displayed

20 superior melt through resistance, higher thermal resistance constant, higher RV density factor and higher density compared with the control fabric of item #1. Thus, the selection of calendering conditions is important to maximize the melt-through resistance and thermal resistance constant of a given polyamide woven fabric.

Table 2

Sample	Fabric Weight (g/m ²)	Thickness (mm)	Fabric Density (kg/m ³)	Fiber RV density factor	Hot Rod Temperature (°C)	Melt-through resistance(s)	Thermal Resistance Constant
Item #1 - Control Fabric	206.5	0.31	666	47952	650	0.6	2.1
					550	0.9	2.7
					450	1.6	3.9
Item #2 - Preferred Process	207	0.22	941	67752	650	0.8	3.9
					550	1.3	5.4
					450	2.0	6.8
Item #3 - Alternative Process	208.7	0.28	745	53640	650	0.7	2.7
					550	1.1	3.6
					450	1.7	4.6

Example 3

5 **[00076]** A further series of woven fabrics were prepared using nylon 6,6 yarn (with an RV in the range of 70-75 and tenacity > 80cN/tex) as shown in Table 3, in order to further investigate the effect of calendering on density, RV density factor and melt-through resistance at differing fabric constructions and loom weaving methods. All examples had a calendered and a non-calendered control fabric comparison. The fabrics were calendered on both the upper and lower
10 surfaces at a pressure of 57 MPa, a temperature of 225°C and a speed of 5 m/min. The fabric weight, thickness, density, RV density factor, melt-through resistance and thermal resistance constant were measured as described herein and the results are presented in Table 4 and Figures 3 to 5 (MTR).

15 **[00077]** The inventors observed that in all cases, fabrics that were calendered had a higher density (density > 850 kg/m³) and a higher RV density factor, compared to the non-calendered control fabrics (density < 700 kg/m³). The inventors also observed a corresponding improvement in the melt-through resistance of the calendered fabrics at each test temperature, as illustrated in Figure 3 (450°C), Figure 4 (550°C) and Figure 5 (650°C), and an improvement in thermal resistance constant. These observations for fabrics made with different constructions and loom
20 weaving methods further confirm the benefit of the increased fabric density induced by the calendering process to enhance melt-through resistance of the fabric.

Table 3

ID	Yarn linear mass density (Dtex)	Construction (ends/dm)	Fiber DPF	Loom
1	470	170x170	3	rapier
2	470	200x200	3	rapier
3	470	190x190	3	water jet
4	470	180x180	6	rapier
5	470	190x190	3	rapier
6	350	235x235	3	air jet
7	470	166x169	3	rapier

Table 4

Calendered Fabrics										Non Calendered Fabric (control)					
ID	Fabric Weight (g/m²)	Thickness (mm)	Fabric Density (kg/m³)	Fiber RV density factor	Melt-through resistance (s); Thermal resistance constant			Fabric Weight (g/m²)	Thickness (mm)	Fabric Density (kg/m³)	Fiber RV density factor	Melt-through resistance (s); Thermal resistance constant			
					450°C	550°C	650°C					450°C	550°C	650°C	
1	180.4	0.20	902	64944	1.9; 7.0	1.3; 5.9	0.8; 4.2	171.3	0.25	685	49320	1.3; 3.8	0.8; 2.9	0.5; 2.2	
2	196.9	0.22	895	64440	2.1; 7.3	1.4; 5.8	0.9; 4.6	192.4	0.28	687	49464	1.7; 4.7	1.1; 3.7	0.7; 2.6	
3	203.7	0.23	905	65160	2.3; 7.5	1.6; 6.3	0.9; 4.3	196.9	0.29	679	48888	1.8; 4.6	1.3; 4.0	0.8; 3.0	
4	194.2	0.22	883	63576	2.1; 7.3	1.5; 6.0	0.9; 4.3	186.9	0.27	692	49824	1.8; 4.9	1.2; 4.0	0.7; 2.9	
5	185.0	0.21	902	64944	1.7; 6.0	1.1; 4.7	0.7; 3.7	184.6	0.28	671	48312	1.3; 3.4	0.8; 2.8	0.5; 1.9	
6	183.0	0.20	915	65880	1.7; 6.5	1.1; 4.8	0.6; 3.3	171.0	0.25	684	49248	1.2; 3.6	0.8; 3.0	0.4; 1.8	
7	179.0	0.19	942	67824	1.7; 6.5	1.1; 5.3	0.7; 3.8	171.0	0.25	684	49248	1.3; 3.8	0.7; 2.4	0.4; 1.7	

Claims

1. A method of making a woven fabric comprising the steps of (i) weaving a spun synthetic polyamide yarn and (ii) subjecting the resulting woven fabric to a High Temperature-High Pressure (HTHP) treatment, to provide a woven fabric having a bulk density of greater than 875 kg/m³ and a fiber relative viscosity (RV) density factor of at least 62,500.
2. A method according to claim 1 wherein said bulk density is at least 900 kg/m³, preferably at least 925 kg/m³, preferably at least 950 kg/m³, preferably at least 975 kg/m³.
3. A method according to claim 1 or 2 wherein the woven fabric is made from polyamide yarns of a single polymer type and titer woven in both the warp direction and weft direction.
4. A method according to any preceding claim wherein the fiber relative viscosity is at least 68, preferably at least 70, preferably at least 72, preferably at least 75, preferably at least 78, preferably at least 85, preferably at least 90, and preferably no more than 150, typically no more than 110, typically no more than 100.
5. A method according to any preceding claim wherein the fiber RV density factor is in the range of from 63,000 to 100,000, preferably from 65,000 to 95,000, preferably from 67,000 to 92,000, preferably at least 70,000, preferably at least 75,000, preferably at least 80,000, preferably at least 85,000.
6. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a thermal resistance constant (X) at 450°C in the range of from 6.0 to 10.0, preferably from 6.2 to 9.0, preferably from 6.5 to 8.6, preferably from 6.5 to 8.0 °C.s.mm⁻¹, and a thermal resistance constant (X) at 650°C in the range of from 3.3 to 6.0, preferably from 3.3 to 5.5, preferably from 3.5 to 5.2, preferably from 3.8 to 5.0 °C.s.mm⁻¹.
7. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a melt-through resistance at 450°C of at least 2.00, preferably at least 2.10, preferably at least 2.20, preferably at least 2.30, preferably at least 2.40, preferably at least 2.50 seconds, preferably at least 2.60 seconds, preferably at least 2.70 seconds.
8. A method according to any preceding claim wherein said yarn has a tenacity from 6.8 to 10.1 g/den.

9. A method according to any preceding claim wherein said yarn has a linear mass density in the range of from 150 to 940 decitex, or in the range of 150 to 750 decitex, preferably from about 400 to about 750 decitex.
- 5 10. A method according to any preceding claim wherein said yarn has from 90 to 300 ends/dm, or from 160 to 240 ends/dm, preferably at least 180 ends/dm, preferably at least 190 ends/dm, and preferably from 180 to 220 ends/dm, preferably wherein the woven fabric exhibits a symmetrical construction.
- 10 11. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) has a total fabric weight in the range of 170 to 260 g/m², and preferably from 190 to 220 g/m².
12. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) has a total thickness of no more than 0.28 mm, preferably no more than 0.25mm preferably no more than 0.24mm, preferably no more than 0.23 mm, preferably no more than 0.22 mm, and typically at least 0.20mm.
- 15 13. A method according to any preceding claim wherein said polyamide is nylon-6,6.
14. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a static air permeability of no more than 6.0, preferably no more than 5.0, preferably no more than 4.0 l/dm²/min, preferably no more than 3.0 l/dm²/min, preferably no more than 2.0, preferably no more than 1.0, preferably no more than 0.5, preferably no more than 0.3, preferably no more than 0.2 l/dm²/min.
- 20 15. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a dynamic air permeability of no more than 700, preferably no more than 600, preferably no more than 500, preferably no more than 400, preferably no more than 300, preferably no more than 200, preferably no more than 150, preferably no more than 100 mm/s.
- 25 16. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a tear strength of the fabric in both the warp and weft directions is at least 120 N, preferably at least 150 N, preferably at least 170 N.
- 30 17. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a tensile strength in each and preferably both of the warp and weft directions, preferably at least 1000N, preferably at least 1500N, preferably at least 2000N, preferably at least 2500N, preferably at least 3000N.
18. A method according to any preceding claim, said yarn being woven in the warp and weft direction to form a top surface of the woven fabric and a bottom surface of the woven

fabric, wherein at least a portion of the yarn on the top surface and/or at least a portion of the yarn on the bottom surface of the woven fabric which is the product of step (ii) have fibers that are fused together.

19. A method according to claim 18 wherein said fibers that are fused together have a permanently modified cross-section.
20. A method according to any preceding claim wherein the woven fabric is uncoated.
21. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a fabric RV of at least 65, preferably at least 70, preferably at least 75, preferably at least 78, preferably at least 80, preferably at least 85, preferably at least 90, and preferably in the range of from 75 to 110, preferably from 78 to 110, preferably from 85 to 100.
22. A method according to any preceding claim wherein the woven fabric which is the product of step (ii) exhibits a fabric RV density factor of at least 55,000, preferably at least 58,000, preferably at least 60,000, and preferably in the range of 55,000 to 95,000, preferably from 58,000 to 90,000, preferably from 60,000 to 88,000, preferably at least 65,000, preferably at least 70,000, preferably at least 75,000, preferably at least 80,000.
23. A method of making an airbag, or a method of improving the resistance to pinhole failure of an airbag, said method comprising the steps of (i) providing a woven fabric comprising spun synthetic polyamide yarn wherein said fabric is made from polyamide yarn woven in the warp direction and weft direction, (ii) subjecting said woven fabric to a High Temperature-High Pressure (HTHP) treatment such that the HTHP-treated woven fabric exhibits a bulk density of greater than 875 kg/m³ and a fabric relative viscosity (RV) density factor of at least 55,000, and (iii) constructing the airbag from said HTHP-treated woven fabric.
24. A method of adjusting the melt-through resistance and/or thermal resistance constant of a woven fabric comprising spun synthetic polyamide yarn, said method comprising the steps of (i) weaving the fabric from a spun synthetic polyamide yarn and (ii) subjecting the resulting woven fabric to a High Temperature-High Pressure (HTHP) treatment, to provide a woven fabric having a bulk density of greater than 875 kg/m³ and a fiber relative viscosity (RV) density factor of at least 62,500.
25. A method according to any preceding claim wherein said HTHP treatment is calendering.
26. A method according to any preceding claim wherein said HTHP treatment is conducted at a temperature in the range of 130 to 240°C, preferably in the range of 220 to 240°C,

and a pressure in the range of from 28 to 115 MPa, preferably in the range of from 35 to 70 MPa, preferably in the range of from about 50 to about 65 MPa.

27. A method according to any preceding claim wherein said HTHP treatment is conducted in the presence of a heat transfer fluid, preferably wherein the heat transfer fluid comprises water, preferably wherein the heat transfer fluid is present in an amount of from 5 to 30, preferably from 10 to 20, preferably from 12 to 18 wt%, based on the weight of the dry fabric.

28. A method according to claim 27 when dependent on any of claims 1 to 25 wherein said HTHP treatment is conducted at a temperature in the range of 100 to 240°C, preferably in the range of 150 to 190°C, and a pressure in the range of from 28 to 115 MPa, preferably in the range of from 35 to 70 MPa, preferably in the range of from about 50 to about 65 MPa.

29. A method according to any preceding claim wherein said HTHP treatment is a calendering step conducted at a line speed of from 5 to 80, preferably from 5 to 70, preferably from 5 to 50 m/min, or at least 10 m/min.

30. A woven fabric obtained or obtainable by the method of any of claims 1 to 22 or claims 25 to 29 when dependent on claims 1 to 22.

31. A woven fabric comprising spun synthetic polyamide yarn, wherein said fabric is made from polyamide yarn woven in the warp direction and weft direction wherein the bulk density of the fabric is greater than 875 kg/m³, and wherein the fabric relative viscosity (RV) density factor is at least 55,000, preferably at least 58,000, preferably at least 60,000, and preferably in the range of 55,000 to 95,000, preferably from 58,000 to 90,000, preferably from 60,000 to 88,000, preferably at least 65,000, preferably at least 70,000, preferably at least 75,000, preferably at least 80,000.

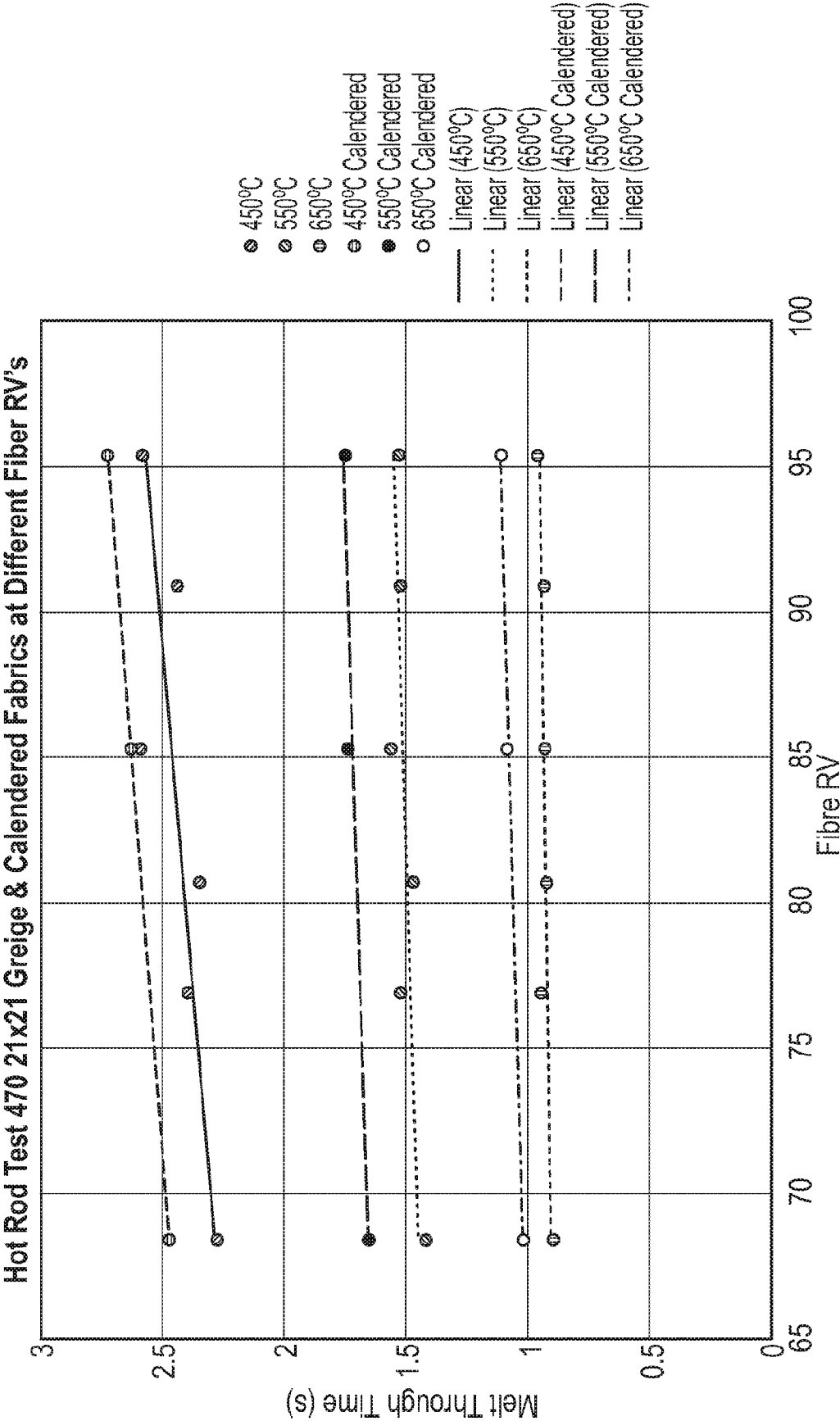
32. A woven fabric according to claim 31 which is a calendered woven fabric.

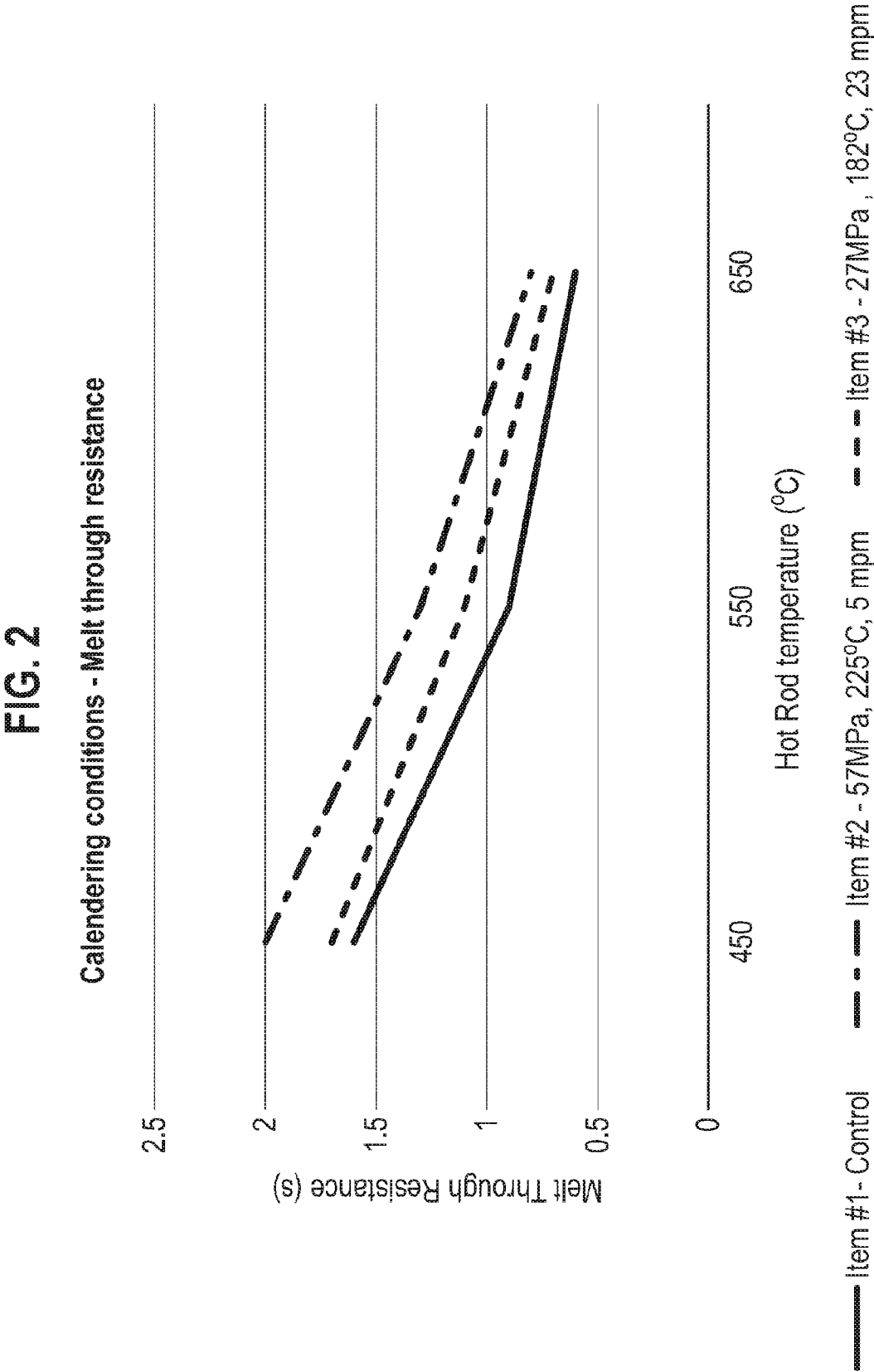
33. A woven fabric according to claim 31 or 32 wherein the woven fabric is as defined in any of claims 1 to 22.

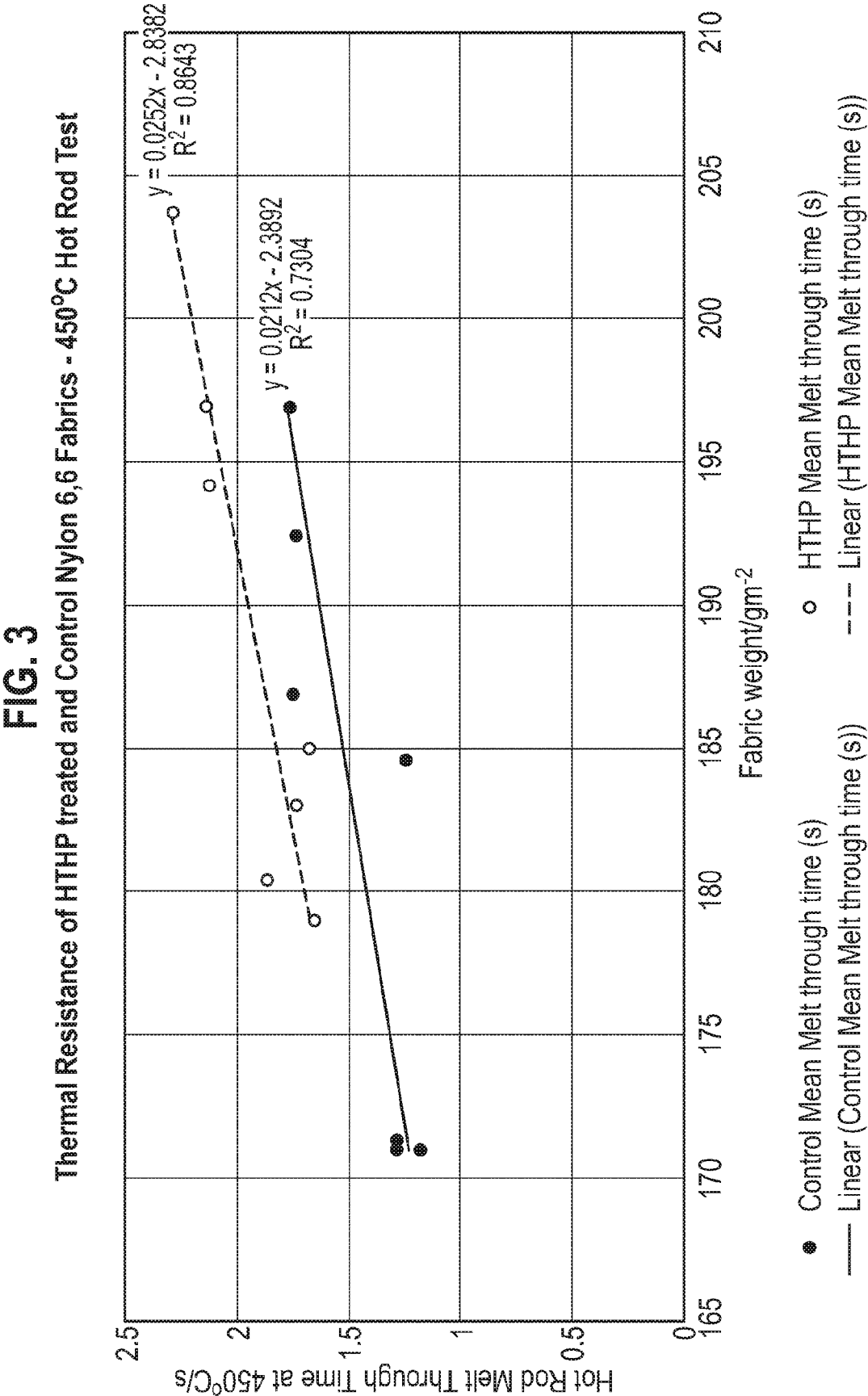
34. An article, preferably an airbag, made from the woven fabric of any of claims 30 to 33.

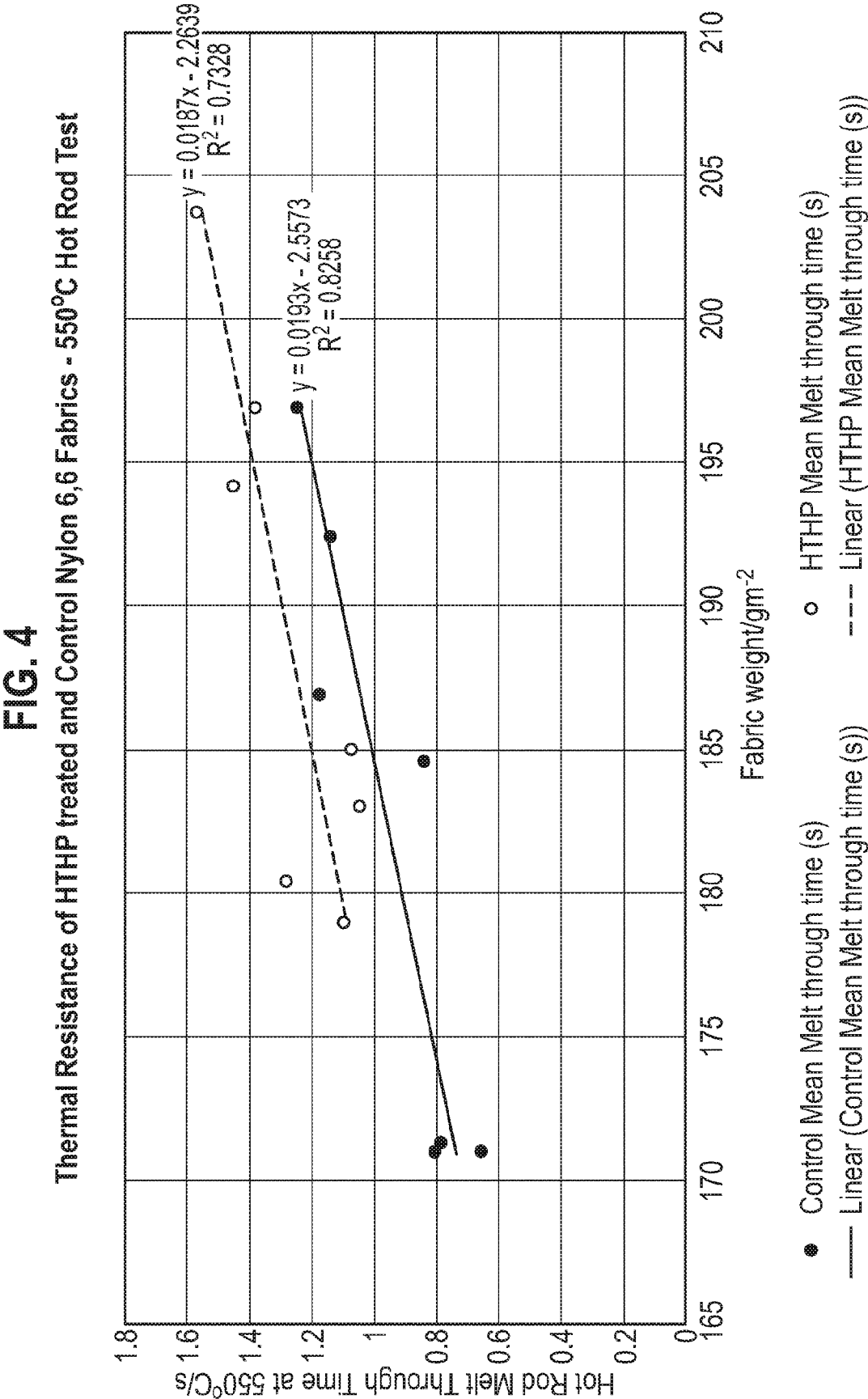
35. The use of a woven fabric as defined in any of claims 30 to 33 to improve the resistance to pinhole failure of an airbag made therefrom.

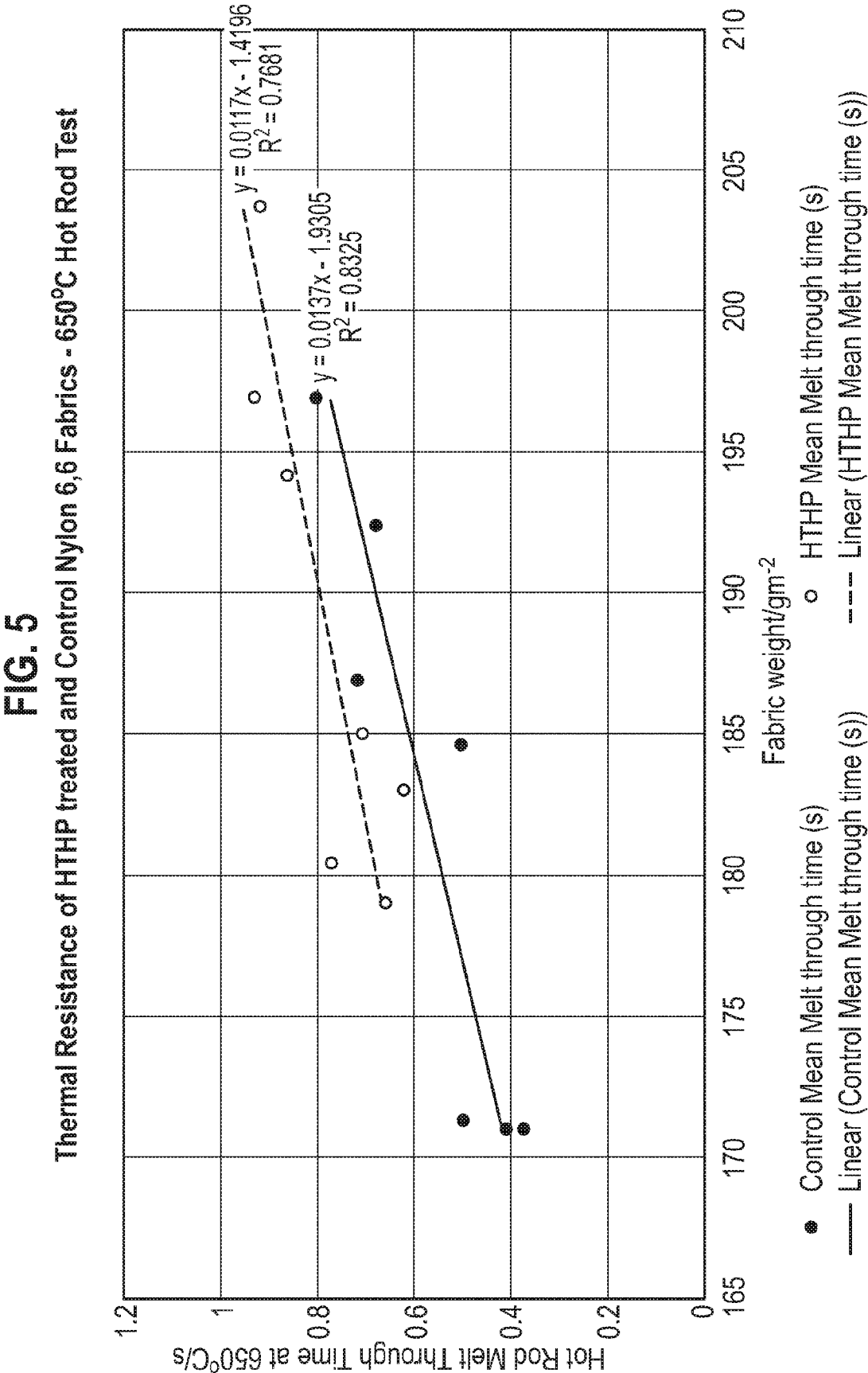
FIG. 1











INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2021/060281

A. CLASSIFICATION OF SUBJECT MATTER INV. D03D1/02 D03D15/283 D03D15/587 D01F6/60 B60R21/235 D02G3/44 D06C15/00		
ADD. 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) D03D D01F B60R D02G D06C		
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		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/265279 A1 (ISE FUMIAKI [JP] ET AL) 18 September 2014 (2014-09-18) abstract claims 1, 10, 12-14 figures 1, 6 paragraph [0001] - paragraph [0005] paragraph [0008] paragraph [0012] paragraph [0021] - paragraph [0026] paragraph [0034] paragraph [0035] paragraph [0045] paragraph [0058] paragraph [0059] paragraph [0061] paragraph [0082] - paragraph [0085] example 1 table 1 ----- -/-	1-35
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* 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 doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "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 17 January 2022		Date of mailing of the international search report 31/01/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Heinzelmann, Eric

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2021/060281

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 4 603297 B2 (ASAHI KASEI FIBERS CORP) 22 December 2010 (2010-12-22) claims 1, 4 paragraph [0002] paragraph [0003] paragraph [0009] paragraph [0010] paragraph [0012] paragraph [0013] paragraph [0024] paragraph [0026] paragraph [0030] paragraph [0039] paragraph [0041] -----	1-19, 21-35
X	JP 2011 168919 A (ASAHI KASEI FIBERS CORP) 1 September 2011 (2011-09-01) claims 1, 4 paragraph [0001] - paragraph [0003] paragraph [0026] - paragraph [0028] paragraph [0037] paragraph [0038] paragraph [0040] paragraph [0041] -----	1-19, 21-35
X	JP 4 733299 B2 (ASAHI KASEI CORP) 27 July 2011 (2011-07-27) claims 1, 3-7 paragraph [0001] - paragraph [0007] paragraph [0012] - paragraph [0013] paragraph [0038] - paragraph [0044] paragraph [0071] -----	1-19, 21-35

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2021/060281

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014265279 A1	18-09-2014	CN 103597131 A	19-02-2014
		EP 2752510 A1	09-07-2014
		JP 5253685 B1	31-07-2013
		JP WO2013084322 A1	27-04-2015
		KR 20140007010 A	16-01-2014
		MX 352851 B	13-12-2017
		US 2014265279 A1	18-09-2014
		WO 2013084322 A1	13-06-2013

JP 4603297 B2	22-12-2010	JP 4603297 B2	22-12-2010
		JP 2005344266 A	15-12-2005

JP 2011168919 A	01-09-2011	JP 5646860 B2	24-12-2014
		JP 2011168919 A	01-09-2011

JP 4733299 B2	27-07-2011	JP 4733299 B2	27-07-2011
		JP 2003020566 A	24-01-2003
