

Method and device for manufacturing an embossed sheet of substrate with a controlled thickness value and a reduced content of clusters**Technical Field**

The invention is in the field of embossing, and more particularly embossing of a sheet of substrate woven or non-woven and comprising any material from a list comprising paper, woven cellulose-based material, non-woven cellulose-based material, natural fibrous material, synthetic fibrous material, porous material, and mixtures thereof.

Background Art

In an International application of the present applicant, having the filing number PCT/IB2023/062474, and being unpublished at the time of filing the present application, an invention is described that is in the field of manufacturing for the inhalable drug delivery system industry, including smoking products in which medical drugs or nicotine may be dispensed in a gas to a user in various inhalable ways, comprising for example vapor, heated tobacco, and conventional burned tobacco as known from cigarettes and cigars, more specifically in a field of embossing, and relating to a component of a filtering element, and the filtering element as such. The manufactured component therein is generally made from sustainable substrates (e.g., paper- or cellulose-based), which is used to produce sustainable cigarette filters, or filters for other various drug delivery devices. Such substrates may undergo a step of accelerated drying, e.g., using forced air drying, which has a direct impact on their thickness stability.

These sustainable substrates of varying thickness are leading – upon their folding and transforming into a filter rod – to filters with varying filling factors (i.e., impact on gas flow / filtering properties) and also on influences on their mechanical properties, e.g., stiffness.

A grammage of these sustainable substrates may vary for instance between 25 gsm and 100 gsm and their thicknesses vary – typically and according to their fabrication process – between 50 μm and 500 μm . Therefore, the mass density of such substrates may typically be found in the region between 0.1 g/cm³ and 1.0 g/cm³.

The sustainable substrate's grammage gives a much better idea as to the actual thickness of a paper. As a general rule, 10–35 gsm is of tissue consistency; 35–70 gsm is lighter textweight, 70–100 gsm is medium textweight, 100–120 gsm is heavy textweight/light cardstock, 120–150 gsm is regular cardstock weight, 150–200 gsm is heavy cardstock, and greater than 200 gsm is super heavy cardstock.

The above-mentioned invention provides a method and an embossing set-up to manufacture from the sustainable substrate an embossed sheet of material that has a controlled material thickness. This may allow to compensate for a material that is uneven prior to embossing, i.e.,

has a variable thickness, and to confer an improved control of draft through a filtering element made using the embossed sheet of material.

The filtering element of a drug-delivery device has a major influence on the customer experience of the end user of such a device and the common practice consists in designing filter elements with predefined Pressure Drop (PD) values for specific products and market segments. This means that the filter-element manufacturing process targets to produce filter-element with predefined PD values and the lowest possible Coefficient of Variation (CV). The present invention is of importance in achieving the latter goal, namely in reducing the CV value and thus increasing the reproducibility of the aforesaid manufacturing process.

It has been found that such manufacturing method and embossing set-up may generate debris from the sustainable substrate, such as for example originating from clusters contained in the sustainable substrate and released from the sustainable substrate at the time of embossing. Indeed, this may also happen with a non-sustainable substrate in case this contains for example clusters that release from the non-sustainable substrate at the time of embossing. As a result, the manufactured may vary and be negatively affected by the debris, despite all care taken. For example, the debris may deposit on surfaces of embossing tools and affect embossing behaviour. It is also possible that the debris gets included in the manufactured embossed sheet of material and any product that makes use of the embossed sheet of material.

The present invention aims to provide a solution to produce an embossed sheet of substrate that offers an improved homogeneity of its thickness value and comprises a reduced content of components susceptible of generating debris.

The invention is particularly advantageous for example when the embossed sheet of substrate is intended for use in a further manufacturing process that aims at obtaining filtering elements as presented herein above, in which the manufacturing process involves a subsequent embossing of the embossed sheet of substrate.

More particularly, the invention advantageously alleviates negative effects produced in the prior art embossing process described in the above cited International application, when embossing a substrate for the manufacturing of the component of the filtering element, and the filtering element as such, or any other product made from the substrate, more particularly for a case in which the substrate presents inhomogeneous thickness values and/or contains clusters prior to embossing. The negative effects may comprise an unacceptably large variance of filtering properties.

Summary of Invention

In a first aspect, the invention provides a method for manufacturing an embossed sheet of substrate. The method is configured to produce a controlled thickness value of the embossed sheet of substrate and to reduce a content of clusters present in the non-embossed substrate. The method comprises steps of providing a sheet of substrate comprising a first material, the sheet of substrate having an average starting thickness; providing an embossing roller system comprising at least a first and a second embossing roller, having respectively a first radial profile and a corresponding second radial profile congruent to the first radial profile, the first radial profile comprising embossing structures protruding from or recessed in a base surface of the first embossing roller, and forming radially oriented ridges and grooves respectively; inserting the sheet of substrate in a nip formed between the first and the second embossing roller; adjusting an embossing pressure between the first and the second embossing roller to obtain a determined nip value of the nip, smaller than the average starting thickness; embossing the sheet of substrate; thereby obtaining the controlled thickness value of the embossed sheet of substrate smaller than the average starting thickness; compressing in the nip at least a first type of cluster comprising the first material inside the embossed sheet of substrate; processing at least a second type of cluster made of a second material different from the first material in any one of the following manners:

compressing and maintaining the at least one second type of cluster in the embossed sheet of substrate;

extracting the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure (P), which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to a surface of the embossed sheet of substrate;

extracting the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure, which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to any one of the base surfaces and the embossing structures of the first and the second embossing rollers.

The method further comprises detaching the debris from the base surfaces and the embossing structures by means of a roller cleaning tool; and removing the detached debris from the embossing roller system by means of an air-depression cleaning system.

In a preferred embodiment, the method further comprises after embossing the sheet of substrate: leading the embossed sheet of substrate through at least an additional debris removal system, thereby deflecting the embossed sheet of substrate on a removal tool of the additional debris removal system, configured to detach debris adhering to the surface of the embossed sheet of

substrate; and removing the detached debris from the debris removal system by means of an additional air-depression cleaning system corresponding to the additional debris removal system.

In a further preferred embodiment, the removal tool to detach debris adhering to the surface of the embossed sheet of substrate comprises any one of the following items of a list comprising: a cylinder comprising a roughened surface configured to be in contact with the embossed sheet of substrate; a curved roughened surface configured to be in contact with the embossed sheet of substrate; a blade comprising an edge configured to be in contact with the embossed sheet of substrate; an ultrasonic wave generator configured to project an ultrasonic beam towards the embossed sheet of substrate.

In a further preferred embodiment, the roller cleaning tool comprises at least a scrapper for each of the embossing rollers, each scrapper comprising an edge configured to be presented towards the roller surface of the corresponding embossing roller, and having a shape fitting congruently in the corresponding radial profile of the embossing roller, and configured in such a way that the debris adhering to any one of the base surface and the embossing structures of the roller surface is removed from the roller surface while the embossing roller rotates.

In a further preferred embodiment, the step of providing the embossing roller system comprises mounting each of the first and the second embossing rollers in a corresponding quick exchange fixture, whereby each of the quick exchange fixtures is removably mounted in a frame.

In a further preferred embodiment, the step of providing the embossing roller system comprises mounting and adjusting the first and the second embossing rollers in a quick exchange cassette, whereby the quick exchange is removably mounted in a frame.

In a further preferred embodiment, the method further comprises providing a further embossing roller system comprising a third and a fourth embossing roller, with further embossing features configured for embossing at least an aerodynamic profile on the embossed sheet of substrate, the embossed aerodynamic profiles being configured to modify in a determined manner flow properties for a gas flow passing through the embossed aerodynamic profiles by creating a gas flow turbulence; inserting the embossed sheet of substrate in a further nip formed between the third and the fourth embossing rollers; further embossing the embossed sheet of substrate.

In a further preferred embodiment, the further embossing roller system is part of a production chain for manufacturing from the sheet of substrate a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element.

In a further preferred embodiment, the step of providing the further embossing roller system comprises mounting each of the third and fourth embossing roller in a corresponding quick exchange fixture, whereby each of the quick exchange fixtures is removably mounted in a frame.

In a further preferred embodiment, the step of providing the further embossing roller system comprises mounting each of the third and fourth embossing roller mounting and adjusting the first embossing roller and the second embossing roller in a quick exchange cassette, whereby the quick exchange is removably mounted in a frame.

In a further preferred embodiment, each of the radially oriented ridges and grooves comprises two contiguous radially directed flanks that define an angle between two contiguous flanks of the radially ridges and grooves that has a value between 75° and 140° .

In a further preferred embodiment, the radially oriented ridges and grooves are described by a top-of-ridge to bottom-of-groove height value situated in a range 0.1 mm and 1.0 mm.

In a further preferred embodiment, the radially oriented ridges and grooves are arranged in a parallel, periodic manner which is described by a dimensional spacing of at least 0.5 mm between two adjacent ridges and grooves.

In a further preferred embodiment, the first and the second embossing rollers are driven and self-synchronized by means of the radial embossing features engaged into each other by applying an embossing pressure between the rollers.

In a further preferred embodiment, the first and the second embossing rollers are driven and synchronized by any means from a list of synchronization means comprising toothed-wheels gears, helicoidal gears, servomotors.

In a further preferred embodiment, the non-embossed sheet of substrate has a grammage in a range between 10 gsm and 150 gsm and a starting average thickness value in a range between 0.02 mm and 1.0 mm.

In a further preferred embodiment, the sheet of substrate comprises any material from a list comprising paper, woven cellulose-based material, non-woven cellulose-based material, natural fibrous material, synthetic fibrous material, porous material, and mixtures thereof.

In a second aspect, the invention provides a system for manufacturing an embossed sheet of substrate. The system is configured to produce a controlled thickness value of the embossed sheet of substrate and to reduce a content of clusters present in the non-embossed substrate. The system comprises an embossing roller system comprising at least a first and a second embossing roller, having respectively a first radial profile and a corresponding second radial profile congruent to the first radial profile, the first radial profile comprising embossing structures protruding from or recessed in a base surface of the first embossing roller, and forming radially oriented ridges and grooves respectively. The embossing roller system further comprises a nip formed between the first and the second embossing roller and configured for inserting therein a sheet of substrate comprising a first material, the sheet of substrate having an average starting thickness; pressure adjusting means configured to adjust an embossing pressure between the

first and the second embossing roller and obtain a determined nip value of the nip, smaller than the average starting thickness; whereby an embossing of the sheet of substrate enables to obtain the controlled thickness value of the embossed sheet of substrate smaller than the average starting thickness; compress at least a first type of cluster comprising the first material inside the embossed sheet of substrate; process at least a second type of cluster made of a second material different from the first material in any one of the following manners:

compress and maintain the at least one second type of cluster in the embossed sheet of substrate;

extract the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure, which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to a surface of the embossed sheet of substrate;

extract the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure (P), which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to any one of the base surfaces and the embossing structures of the first and second embossing rollers.

The system further comprises a roller cleaning tool configured to detach the debris from the base surfaces and the embossing structures; and an air-depression cleaning system configured to remove the detached debris from the embossing roller system.

In a preferred embodiment, the system further comprises at least an additional debris removal system, configured to further lead through the embossed sheet of substrate, a removal tool in the additional debris removal system configured to deflect the embossed sheet of substrate, and configured to detach debris adhering to the surface of the embossed sheet of substrate; and an additional air-depression cleaning system corresponding to the additional debris removal system, configured for removing the detached debris from the debris removal system by means of an additional air-depression cleaning system.

In a further preferred embodiment, the removal tool to detach debris adhering to the surface of the embossed sheet of substrate comprises any one of the following items of a list comprising: a cylinder comprising a roughened surface configured to be in contact with the embossed sheet of substrate; a curved roughened surface configured to be in contact with the embossed sheet of substrate; a blade comprising an edge configured to be in contact with the embossed sheet of substrate; an ultrasonic wave generator configured to project an ultrasonic beam towards the embossed sheet of substrate.

In a further preferred embodiment, the roller cleaning tool comprises at least a scrapper for each of the embossing rollers, each scrapper comprising an edge configured to be presented towards

the roller surface of the corresponding embossing roller, and having a shape fitting congruently in the corresponding radial profile of the embossing roller, and configured in such a way that the debris (302) adhering to any one of the base surface and the embossing structures of the roller surface is removed from the roller surface while the embossing roller rotates.

In a further preferred embodiment, the system further comprises at least two quick exchange fixtures, respectively configured to mount each of the first and the second embossing rollers, whereby each of the quick exchange fixtures is removably mounted in a frame.

In a further preferred embodiment, the system further comprises a quick exchange cassette configured to comprise the first and the second embossing rollers adjusted inside the quick exchange cassette, and the quick exchange cassette is removably mounted in a frame.

In a further preferred embodiment, the system further comprises a further embossing roller system comprising a third and a fourth embossing roller, with further embossing features configured for embossing at least an aerodynamic profile on the embossed sheet of substrate, the embossed aerodynamic profiles being configured to modify in a determined manner flow properties for a gas flow passing through the embossed aerodynamic profiles by creating a gas flow turbulence. The further embossing roller system further comprises a further nip formed between the third and the fourth embossing rollers, and configured for inserting therein the embossed sheet of substrate.

In a further preferred embodiment, the further embossing roller system is part of a production chain for manufacturing from the sheet of substrate a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element.

In a further preferred embodiment, the system further comprises at least two further quick exchange fixtures, respectively configured to mount each one of the third and fourth embossing rollers, whereby each of the further quick exchange fixture is removably mounted in a frame.

In a further preferred embodiment, the system further comprises a further quick exchange cassette configured to comprise the third embossing roller and the fourth embossing roller adjusted inside the further quick exchange cassette, and the further quick exchange cassette is removably mounted in a frame.

In a further preferred embodiment, each of the radially oriented ridges and grooves comprises two contiguous radially directed flanks that define an angle between two contiguous flanks of the radially ridges and grooves that has a value between 75° and 140°.

In a further preferred embodiment, the radially oriented ridges and grooves are described by a top-of-ridge to bottom-of-groove height value situated in a range 0.1 mm and 1.0 mm.

In a further preferred embodiment, the radially oriented ridges and grooves are arranged in a parallel, periodic manner which is described by a dimensional spacing of at least 0.5 mm between two adjacent ridges and grooves.

In a further preferred embodiment, the first and the second embossing rollers are configured to be driven and self-synchronized by means of the radial embossing features engaged into each other by applying an embossing pressure between the rollers.

In a further preferred embodiment, the first and the second embossing rollers are driven and synchronized by any means from a list of synchronization means comprising toothed-wheels gears, helicoidal gears, servomotors.

In a further preferred embodiment, the non-embossed sheet of substrate has a grammage in a range between 10 gsm and 150 gsm and a starting average thickness value in a range between 0.02 mm and 1.0 mm.

In a further preferred embodiment, the sheet of substrate comprises any material from a list comprising paper, woven cellulose-based material, non-woven cellulose-based material, natural fibrous material, synthetic fibrous material, porous material, and mixtures thereof.

Brief Description of the Figures

The invention will be better understood through the description of example embodiments of the invention and in reference to the Figures, wherein

Figure 1 shows an example of a system for manufacturing an embossed sheet of substrate according to the invention;

Figure 2 shows an example of a piece of a sheet of substrate prior to embossing, and which comprises clusters;

Figure 3 shows an example of a piece of an embossed sheet of substrate as obtained with the invention;

Figure 4 shows a further example of the system for manufacturing an embossed sheet of substrate according to the invention;

Figure 5(A) shows a preferred embodiment of the system for manufacturing an embossed sheet of substrate with additional debris removal systems according to the invention;

Figure 5(B) shows a cross section through an embossed sheet of substrate before and after passing through an additional debris removal system;

Figure 6 shows a preferred embodiment for a set of embossing rollers driven by toothed wheels;

Figure 7 contains an example of an embossed sheet of substrate and magnified cross-sections of embossing rollers used for embossing;

Figure 8 contains a further example of an embossed sheet of substrate and a magnified cross-section of embossing rollers used for embossing;

Figure 9 contains yet a further example of an embossed sheet of substrate and magnified cross-sections of embossing rollers used for embossing;

Figure 10 contains yet a further example of an embossed sheet of substrate and a magnified cross-section of embossing rollers used for embossing;

Figures 11(A)-11(C) contain views of examples for quick-exchange devices configured for housing a set of embossing rollers according to the invention;

Figure 12 contains a view of a system for manufacturing an embossed sheet of substrate with an example embodiment of a roller cleaning tool in form of scrappers according to the invention;

Figure 13 contains two views of example embodiments for any of the embossing rollers according to the invention;

Figure 14 contains a view of a system for manufacturing an embossed sheet of substrate with a schematical illustration of two different types of gears for driving and synchronizing the embossing rollers according to the invention;

Figure 15 contains a view of an embossing roller with ring-shaped zones at its extremities that comprise axially oriented ridges and grooves used to drive and synchronize embossing rollers according to an example of the invention;

Figure 16 contains a schematic illustration of a set of embossing rollers with ring-shaped shoulders at their extremities;

Figure 17 contains a further schematic illustration of a set of embossing rollers with ring-shaped shoulders at their extremities;

Figure 18 illustrates a preferred embodiment of the system for manufacturing an embossed sheet of substrate according to the invention, where it is a part of an online production line for manufacturing a filter element;

Figure 19 illustrates a further preferred embodiment of the system as in Figure 18 with additional debris removal systems according to the invention;

Figure 20 illustrates a further example of an embossed sheet of substrate further embossed according to the invention, bearing aerodynamic profiles;

Figure 21 schematically illustrates an obtaining of filtering elements using an embossed sheet of substrate as resulting from the invention;

Figure 22 schematically illustrates how a filtering element, in this case a cigarette filter, may be mounted to a tobacco containing section in order to obtain a cigarette according to prior art;

Figure 23 schematically illustrates a structure of an inhalable drug delivery device according to prior art;

Figure 24 contains a flowchart illustrating an example embodiment of a method for manufacturing an embossed sheet of substrate according to the invention.

Same references will be used to designate same or similar features that appear throughout the Figures.

Glossary

With regard to a sheet of substrate

- **cluster**: an agglomeration of matter embedded in a sheet of substrate, originating from a substrate manufacturing process and presenting locally different physical properties than the substantial rest of the substrate; the cluster may consist of the same matter as the substantial rest of the substrate (e.g., cluster of fibers) and locally exhibit a higher mass density, or it may consist of a foreign matter (e.g., additives, impurities) and locally exhibit a higher hardness than the substantial rest of the substrate;
- **debris**: an agglomeration of matter, initially embedded in the sheet of substrate, which upon embossing according to the invention is ejected /separated from the substrate;
- **woven** substrate: a fibrous substrate (e.g., natural or synthetic fibers), in which the substrate substantially consists of interlaced fibers;
- **non-woven** substrate: a substrate consisting of non-fibrous material, of short fibers, and of long fibers, which are bonded together by chemical means or by mechanical or heat treatment;
- **average starting thickness**: the mean value of all thickness values of the non-embossed sheet of substrate measured at a plurality of spots along the substrate.

With regard to a filtering element

- **resistance to draw** (RTD), or **pressure drop** (PD): the amount of suction that must be used to pull a gas flow a filter, usually given as the pressure required to force air through the filter at the rate of 17.5 ml/sec;

- **coefficient of variation (CV)**: the ratio between the standard deviation and the mean value of the individual PD values measured for the filtering elements of a production batch; as a statistical value, CV provides an indication about the reproducibility of a production method, whereas CV values of 5% or less indicate a stable process.

With regard to a filter-element production line

- **online**: the embossing roller system is directly integrated the filter-element production line;
- **atline**: the embossing roller system is integrated into an adjacent production flow, next to the filter-element production line;
- **offline**: the embossing roller system is integrated into the substrate production line, whereby the embossed substrate is used to manufacture filter elements on a different production line.

Detailed Description of Example Embodiments of the Invention

The inventive system and method for manufacturing an embossed sheet of substrate result from ecology-motivated research which for example aims to replace conventional cellulose acetate cigarette filters, while at least maintaining their well-established filtering properties (e.g., resistance to draw and its coefficient of variation), with other categories of suitable, sustainable sheet substrates, more preferably with filters made of paper-based materials, or any material from a list comprising paper, wool, plant- or animal-based fibrous material. The invention provides a method and a system configured for manufacturing an embossed sheet of substrate, and for producing a controlled thickness value of the embossed sheet of substrate, that may be used as a component of a filtering element and that may further be embossed to comprise further embossed features configured for influencing a flow of a mainstream gas flow traversing the filtering element. The embossing according to the invention also reduces a content of clusters present in the non-embossed substrate, whereas both the constancy of the controlled thickness value of the embossed sheet substrate and the reduced content of clusters have a direct positive impact on the reduction of the statistic variations of the properties of the filtering elements obtained through folding of the embossed sheet of substrate.

Referring now to **Figure 1**, this shows an example of a system for manufacturing an embossed sheet of substrate according to the invention. A sheet of substrate **101** is embossed using an embossing roller system **102**, in order to obtain an embossed sheet of substrate **100** with a controlled thickness value and a reduced content of clusters present in the non-embossed substrate **101** (clusters not illustrated in **Figure 1**). According to a feed direction **112**, the sheet of substrate **101** to be embossed is guided using optionally at least a deflection roller **113**, into a nip **105** between a first **103** embossing roller and a second **104** embossing roller, which bear

congruent radial embossing features (not represented). More precisely the first embossing roller **103** has a first radial profile and the second embossing roller **104** has a corresponding second radial profile congruent to the first radial profile. The first radial profile comprises embossing structures protruding from or recessed in a base surface of the first embossing roller **103** and forming radially oriented ridges and grooves respectively. The embossing roller system **102** may comprise pressure P applying means suggested by a set of opposing arrows. The system for manufacturing an embossed sheet of substrate further comprises roller cleaning tools **106** and **107** configured to detach the debris (debris not illustrated) from the base surfaces and the embossing structures, and thus located in front of the rotating embossing rollers **103** and **104**. The system for manufacturing an embossed sheet of substrate further comprises an air-depression cleaning system **108**, **109**, configured to remove the detached debris from the embossing roller system **102**, for example by exhausting the detached debris. For subsequent Figures and considerations, zones **110** and **111** are respectively indicated on the sheet of substrate to be embossed **101** and on the embossed sheet of substrate **100** embossed according to the invention.

Referring now to **Figure 2** this shows an example of a piece of the sheet of substrate prior to embossing, and which comprises substrate clusters. **Figure 2** shows a cross-sectional view **201** along a line **204** from a zone **110** of the sheet of substrate **101** (as shown in **Figure 1**) to be embossed according to the invention. The cross-sectional view **201** illustrates the sheet of substrate **101** prior to embossing, notably fibers **200** giving the sheet of substrate **101** its basics structure; the fibers **200** may be of natural or synthetic origin and they may be present in a woven or non-woven manner (not exhaustively illustrated). Main issues affecting the sheet of substrate **101**, which are addressed by the invention, comprise substantially different substrate thickness values **203** and a presence of clusters **202** that are embedded in and even protruding from a surface of the sheet of substrate **101**, as depicted in the cross-sectional view **201**.

Referring now to **Figure 3** this shows an example of a piece of the embossed sheet of substrate **100** as obtained with the invention. **Figure 3** shows a cross-sectional view **301** along a line **302** from a zone **111** of the embossed sheet of substrate **100** (as shown in **Figure 1**) embossed according to the invention, with a controlled thickness value and a reduced content of clusters. Lines **300** schematically illustrate ridges and grooves embossed by means of the radial embossing features present on the embossing rollers (not represented) and the cross-sectional view **301** originates from the embossed sheet of substrate **100**. The fibers **200** give the embossed sheet of substrate **100** its basics structure. The fibers **200** may be of natural or synthetic origin and they may be present in a woven or non-woven manner (not exhaustively illustrated). The cross-sectional view **301** shows a substantially constant thickness value **303** and crushed and downsized clusters **304** still embedded in the embossed sheet of substrate **100**, as well as clusters **305** and **306**, possibly downsized, and respectively still adhering as debris at a

surface of the embossed sheet of substrate **100**, or already detached as debris from the sheet of substrate **100**, to adhere to the surfaces or the embossing rollers (not represented).

Referring now to **Figure 4** this shows a further example of the system for manufacturing an embossed sheet of substrate according to the invention similar as in **Figure 1** but extended with an additional embossing roller bearing radial embossing structures (structures not illustrated). The sheet of substrate **101** is embossed using a three-rollers embossing system **400**, in order to obtain an embossed sheet of substrate **100** with a controlled thickness value and with a reduced content of clusters. According to the feed direction **112**, the sheet of substrate to be embossed **101** is guided using the optional deflection roller **113**, to the embossing rollers **401**, **402**, **403** bearing radial embossing features (not represented). The depicted system for manufacturing an embossed sheet of substrate further comprises roller cleaning tools **106** and **107** configured to detach the debris (debris not illustrated) from the embossing rollers, thus located in front of the rotating embossing rollers **401** and **403**. The system for manufacturing an embossed sheet of substrate further comprises an air-depression cleaning system **108**, **109**, configured to remove the detached debris from the embossing roller system **400**, for example by exhausting the detached debris.

Referring now to **Figure 5(A)** this shows a preferred embodiment of the system for manufacturing an embossed sheet of substrate with additional debris removal systems according to the invention, while **Figure 5(B)** shows a cross-sectional view through an embossed sheet of substrate before and after passing through an additional debris removal system. The system for manufacturing an embossed sheet of substrate produces an embossed sheet of substrate **507** with a controlled thickness value and with a substantially reduced content of clusters. As indicated by the feed direction **112**, the sheet of substrate **101** to be embossed is fed into the nip (not represented) between the first **103** and the second **104** embossing rollers, which bear radial embossing features (not represented), and which respectively rotate in front of the roller cleaning tools **106** and **107**, whereas the detached debris (not represented) are exhausted from the embossing system using the air-depression cleaning system **108**, **109**. The cross-sectional view from the zone **301** of the embossed sheet of substrate **100**, with controlled thickness value and with reduced content of clusters is also depicted in **Figure 5(B)** and it illustrates the crushed and downsized clusters **304** embedded in the embossed sheet of substrate **100** and the downsized clusters **305** still adhering at a surface of the embossed sheet of substrate **100**. In a further process step of this embodiment, the embossed sheet of substrate **100** with controlled thickness value and with reduced content of clusters, passes through at least an additional debris removal system **505**, **506**, mainly comprising an additional debris removal means **501**, **502** (e.g., a rotating roughened cylinder) and an air-depression cleaning device **503**, **504**. The additional debris removal means may be embodied by a roughened (preferably with a mean surface roughness value R_a below $1.0\ \mu\text{m}$) metallic or ceramic curved surface configured to be in contact with the embossed sheet of substrate cylinder, or by an edge configured to be in contact with the

embossed sheet of substrate, or by an ultrasonic wave generator configured to project an ultrasonic beam towards the embossed sheet of substrate, enabling the detachment of substrate clusters **305** from the sheet of substrate **100**. A further cross-sectional view **500**, from the embossed sheet of substrate **507** with a controlled thickness value and with a substantially reduced content of clusters, shows the remained crushed and downsized clusters **304** still embedded in the embossed sheet of substrate **507** is also depicted in **Figure 5(B)**.

Figure 6 shows a preferred embodiment for a set of embossing rollers driven by toothed-wheels, in which the first **103** and the second **104** embossing rollers are driven by respective toothed-wheels located at their extremities. The first embossing roller **103** comprises as illustrated by a zone **600** a first radial profile comprising embossing structures protruding from or recessed in a base surface of the first embossing roller, and forming radially oriented ridges and grooves respectively (detail not represented in the figure) and the second embossing roller **104** comprises as illustrated by a zone **601** a second radial profile congruent to the first radial profile. The zone **600** on the first embossing roller **103** and the zone **601** on the second embossing roller **104** are defined in a symbolic schematic manner and their hatching representation will be used throughout the subsequent figures and considerations.

Figure 7 contains an example of the embossed sheet of substrate **100** and magnified cross-sections **709** and **710** of embossing rollers used for embossing. More precisely, **Figure 7** shows a view from above of the zone **111** from the sheet of substrate **100** embossed according to the invention, with a controlled thickness value and with a reduced content of clusters, the embossed sheet of substrate bearing recessed axial grooves **701** and protruded axial ridges **700**. The embossed protruded ridges **700** and the recessed grooves **701** are arranged in a parallel manner described by the dimensional period parameter I . In the cross-sectional views **709**, **710** illustrating two variants of a zone of a nip between the embossing rollers **103** and **104** used to obtain the embossed sheet of substrate **100**, and which both correspond to a symbolic line **708** along the embossed sheet of substrate **100**, obtuse-angled embossing features **703**, **705** corresponding to the embossed ridges **700**, obtuse flank-angled embossing features **702**, **704** corresponding to the embossed grooves **701**, the top-of-ridge to bottom-of-groove height value h , as well as nip thickness values **706**, **707** are illustrated. The obtuse flank-angled embossing features **703**, **705** and **702**, **704** respectively depicted in **709**, **710** may have substantially identical geometrical dimension, whereas the features **704**, **705** show sharp edges and the features **702**, **703** exhibit slightly rounded (e.g., with a radius between 0.02 and 0.05 mm) edges.

Figure 8 contains a further example of the embossed sheet of substrate and a magnified cross-section of embossing rollers used for embossing. As such, **Figure 8** illustrates a detailed view from above of the zone **111** from the embossed sheet of substrate **100** embossed according to the invention, with controlled thickness value and with reduced content of clusters, which further contains recessed axial grooves **801** and protruded axial ridges **800**. The embossed protruded

ridges **800** and the recessed grooves **801** are arranged in a periodic parallel manner described by the dimensional period parameter l . In a cross-sectional view **805** from a zone of a nip between the embossing rollers **103** and **104** used to obtain the embossed sheet of substrate **100**, which further corresponds to a symbolic line **806** along the embossed sheet of substrate **100**, embossing features **803** corresponding to the embossed ridges **800**, embossing features **802** corresponding to the embossed grooves **801**, both **802** and **803** with a substantial sinusoidal profile, the top-of-ridge to bottom-of-groove height value h , as well as a nip thickness value **804** are depicted.

Figure 9 contains yet a further preferred example of the embossed sheet of substrate and magnified cross-sections of embossing rollers used for embossing. **Figure 9** illustrates a view from above of the zone **111** from the sheet of substrate **100** embossed according to the invention, with a controlled thickness value and with a reduced content of clusters, which further contains recessed grooves **901** and protruded ridges **900**, whereas the embossed ridges are disconnected by zones **906** in which the embossed sheet of substrate **100** maintains the height level of the grooves **901**. The embossed protruded ridges **900** are arranged in an array-like manner described by the dimensional period parameters p and l . In the cross-sectional views **910**, **911** illustrating two variants of a zone of a nip between the embossing rollers **103** and **104** used to obtain the embossed sheet of substrate **100**, and which both correspond to a symbolic line **909** along the embossed sheet of substrate, obtuse flank-angled embossing features **902**, **903** corresponding to the embossed ridges **900**, base roller surfaces **907**, **908** corresponding to the discontinuities **906**, the top-of-ridge to bottom-of-groove height value h , as well as a nip thickness value **904**, **905** are illustrated. The obtuse flank-angled embossing features **902**, **903** respectively depicted in **910**, **911** may have substantially identical geometrical dimension, whereas the features **903** show sharp top edges and the features **902** exhibit slightly rounded (e.g. with a radius between 0.02 and 0.05 mm) top edges.

Figure 10 contains yet a further example of the embossed sheet of substrate and a magnified cross-section of embossing rollers used for embossing. **Figure 10** contains a detailed top view from the zone **111** from the embossed sheet of substrate **100** embossed according to the invention, with the controlled thickness value and with the reduced content of clusters, which further contains recessed axial grooves **1001** and protruded axial ridges **1000**, whereas the embossed ridges are disconnected by zones **1002** in which the embossed sheet of substrate **100** maintains the height level of the grooves **1001**. The embossed protruded ridges **1000** arranged in an array-like manner are described by the dimensional period parameters p and l . In a cross-section view **1007** from a zone of a nip between the embossing rollers **103** and **104** used to obtain the embossed sheet of substrate **100**, which further corresponds to a symbolic line **1006** along the embossed sheet of substrate, embossing features **1003** with a substantially sinusoidal profile and corresponding to the embossed ridges **1000**, base roller surfaces **1004** corresponding

to the discontinuities **1002**, the top-of-ridge to bottom-of-groove height value h , as well as a nip thickness value **1005** are illustrated.

Flank angles of ridges and grooves

The ridges and grooves defined by the embossing profiles contained by the first **103** and the second **104** embossing rollers have manyfold purposes, namely (i) to homogenize the substrate thickness of the sheet of substrate (i.e., to flatten it), (ii) to induce a certain gradient of the applied embossing pressure, and (iii) to create zones (i.e., the bottom of roller grooves) to temporarily accommodate the debris ejected from the embossed substrate. Whereas a rather flat roller surface would mainly fulfil the former aim, the latter would imply the opposite, namely a high density of grooves. Considerations related to the high penetrating effect of ridges with very acute flank angles and the lack of effects related to ridges of with very obtuse flank angles, further corroborated with embossing trials on woven and non-woven substrates lead to a range between 75° and 140° for the flank angles, most preferably between 80° and 120° , this combined with a profile heights in a range between 0,1 mm and 1.0 mm. The necessity of a large number of grooves to temporarily accommodate the debris, together with the combination between the aforementioned flank angle and profile height values give a lateral spacing between two adjacent ridges or grooves larger than 0,5 mm, most preferably between 0,5 mm and 20 mm.

Figures 11(A)-11(C) contain views of examples for quick-exchange devices configured for housing a set of embossing rollers according to the invention. The embossing rollers **103** and **104** may be removably housed in a quick-exchange device, generically illustrated under reference **1100** in **Figure 11(A)**. In a preferred embodiment **1106** of such a quick-exchange device, an axle of at least one of the rollers **103**, **104** is movable in all three coordinate directions (not illustrated) in order to allow a self-synchronization of the embossing rollers. As shown in **Figure 11(B)**, the quick-exchange device comprises a frame **1101** having two seats intended to receive respective roller fixtures **1102** and **1103**, whereas the roller fixture **1103** serves for mounting the roller **104**, which is driven by a here non-represented external drive, and roller fixture **1102** serves for mounting the roller **103**. In a further preferred embodiment **1107** shown in **Figure 11(C)** of the quick-exchange device, the rollers **103** and **104** are mounted in a cassette **1104**, which contains means (not represented) for adjusting and correcting the positions and the rotation axes of the rollers **103** and **104**, and which is removably mounted in a frame **1105**. In preferred embodiments, the roller **103** is driven by the externally driven roller **104** via gearwheels (not represented) located at one end of the rollers. However, other synchronizing means, e.g. electric servomotors, may also be used.

Figure 12 contains a view of a system for manufacturing an embossed sheet of substrate with an example embodiment of a roller cleaning tool in form of scrappers according to the invention. In

this example embodiment of the invention, the detachment of debris from the surfaces of rollers **103**, **104** is carried out by means of metallic (e.g. brass) or ceramic (e.g. oxides, nitrides, carbides) adapted-shape scrappers **1202** and **1203**. The rollers **103**, **104** and the scrappers **1202**, **1203** are respectively mounted on the roller fixtures **1102** and **1103**, which are themselves part of a quick-exchange device (not represented). However, the quick-exchange device is optional, and the scrappers may be attached to any form of roller supports. To obtain an optimal debris removal from the roller surfaces, the specific edge shape geometries **1204**, **1205** of the scrappers **1202**, **1203** respectively shall be congruent to the embossing structures (i.e., ridges and recesses, not represented) present on the surfaces of rollers **103**, **104**. In a further embodiment, optional means **1201** of lateral displacement are provided for the roller fixture **1102**, in order to allow a self-synchronization of the embossing rollers, by maintaining the matching scrapper positions.

Figure 13 contains two views of example embodiments for any of the embossing rollers according to the invention. More precisely, **Figure 13** illustrates an example embodiment for any one of embossing rollers **103** or **104**, which comprises a rotation axis **1303**, a roller surface **1300** and a toothed wheel **1301** at one extremity of the one embossing roller, enabling the one embossing roller **103** or **104** to be driven by a motor assembly having a corresponding toothed wheel (not represented) and to be synchronized with the other one of the embossing rollers **103** or **104** (other one not represented in **Figure 13**). The embossing features present on the roller surface **1300** are not represented explicitly. **Figure 13** also shows a further example embodiment for any one of embossing rollers **103** or **104**, in which the embossing roller does not comprise any toothed wheel. In this example any one of embossing rollers **103** or **104** is typically driven and synchronized with the other one of the rollers **103** and **104** (not illustrated in the **Figure 13**) by a servo motor mechanism (not represented) that directly rotates the rotation axis **1303**. Embossing features present on a roller surface **1302** are not represented explicitly.

Figure 14 contains a view of a system for manufacturing an embossed sheet of substrate with a schematical illustration of two different types of gears for driving and synchronizing the embossing rollers according to the invention. **Figure 14** illustrates preferred embodiments for driving and synchronizing the embossing rollers **103** and **104**, belonging to an embossing roller system **1402**, according to the invention. The feed direction of the sheet of substrate **101** and of the embossed sheet of substrate **100** is given by the arrows **112**, whereas **Figure 14** also illustrates the adapted-shape scrappers **1202** and **1203**, the air-depression cleaning systems **108** and **109**, as well as the at least one optional deflection roller **113**. In a preferred embodiment, toothed wheels **1301** may be used to drive and synchronize the embossing rollers **103** and **104**, whereas in a further preferred embodiment depicted in the view **1400** helicoidal gears **1401** are used to drive and synchronize the embossing rollers instead of the toothed wheels **1301**.

Figure 15 contains a view of an embossing roller with ring-shaped zones at its extremities that comprise axially oriented ridges and grooves used to drive and synchronize embossing rollers according to an example of the invention. **Figure 15** illustrates a variation of a first embossing roller **1500** (the designation here is similar to the first embossing roller **103**), part of a preferred embodiment of an embossing roller system according to the invention (not illustrated), the variation of the first embossing roller **1500** containing a zone **1501**, which extends all around the roller **1500** and substantially occupying a majority of its lateral surface, and two zones **1502**, all around the roller **1500** and substantially located at its extremities. The zone **1501** contains radially orientated ridges and grooves, to obtain an embossed sheet of substrate with controlled thickness and with reduced content of clusters, the zones **1502** contain substantially similar ridges and grooves, except that they are axially orientated, that may be used to drive the variation of the first embossing roller **1500** and synchronize it with a second embossing roller of the used embossing roller system (not represented).

Figure 16 contains a schematic illustration of a set of embossing rollers with ring-shaped shoulders at their extremities. More precisely **Figure 16** represents a set of embossing rollers **1601**, **1602**, bearing protrusion and recess embossing features (not represented), each comprising at a corresponding extremity a toothed wheel **1603**, **1604**, the teeth of which intertwine to synchronously drive the embossing rollers **1601**, **1602**, to rotate about respective rotation axes **1605**, **1606**. The embossing rollers **1601**, **1602**, further each comprise two ring-shaped shoulders **1607**, **1608**, one towards each extremity of the respective embossing roller **1601**, **1602**, and configured such that a ring-shaped shoulder on one embossing roller faces a corresponding ring-shaped shoulder of the opposite embossing roller. The ring-shaped shoulders **1607**, **1608**, are generally designed to form a ring which centered on the rotation axis of the embossing roller, whose circumference protrudes from a base surface of the embossing roller where it is located. This level of detail is not illustrated in **Figure 16** to maintain a better readability. **Figure 16** further represents two magnified views **1609**, **1610**, of areas where the ring-shaped shoulders **1607** and **1608** are resting on each other as may be the case during embossing. This is substantiated by distance **1611** between the ring-shaped shoulders **1607** and **1608** being 0, while a nip **1612** is maintained between the embossing rollers **1601** and **1602** with a determined nip width value n separating a base surface **1614** of the embossing roller **1601** from an opposite base surface **1613** of the embossing roller **1602**. The base surfaces are schematically represented and in the views **1609** and **1610** do not comprise any embossing features in the example of **Figure 16**. The determined nip width value n of the nip **1612** enables to insert a sheet of substrate in it (sheet of substrate not represented) for embossing, in order to obtain a sheet of substrate with a controlled thickness and a reduced content of surface clusters.

In a further example represented in **Figure 17** the ring-shaped shoulders of **Figure 16** may be replaced by radial recesses **1701** and **1702**, which each form recesses in the embossing rollers **1601** and **1602** respectively as compared to the base surfaces **1613** and **1614**. Hence, as

represented in the two magnified views **1706** and **1707**, when the embossing rollers **1601** and **1602** are pressured one towards the other, as is depicted by arrows **1705** in the radial recesses **1701** and **1702**, their base surfaces **1613** and **1614** may be coming into contact such that a distance **1703** tends to become similar to that of a sheet of substrate inserted therein for embossing (not represented), and a distance **1704** between radial recesses **1701** and **1702** facing each other from one embossing roller to the other is greater than 0. The pressure depicted by the arrows **1705** may be exerted by pressuring means comprised in the embossing set-up (not represented), well known in the prior art, for example by hydraulic or pneumatic pressuring means.

The embodiments illustrated in the foregoing Figures are applicable to any one of the following manners to integrate an embossing system to emboss a sheet of substrate with a controlled thickness value and a reduced content of clusters in a filtering-element production line: online, atline, offline. The following two Figures are detailing preferred embodiments of online integration.

Figure 18 illustrates a preferred embodiment of the system for manufacturing an embossed sheet of substrate according to the invention, where it is a part of an online production line for manufacturing a filter element. More precisely, **Figure 18** illustrates a preferred embodiment of the system for manufacturing an embossed sheet of substrate **1801** according to the invention, as a part of an online production line for manufacturing a filter element of length L (filter element and length not represented). The online production line further comprises for example a compacting device **1809** comprising a funnel **1807** into which a further embossed sheet of substrate **1805** is fed, folded, and formed into a filter rod **1808** output by the compacting device **1809**. Hence the further embossed sheet of substrate **1805** is compacted with the funnel **1807**. The filter rod **1808** may be pulled by means of a pulling jig **1810** to a further process step **1811** of cutting. The production line contains the embossing system **1801**, according to the invention, to produce the embossed sheet of substrate **100** with controlled thickness value and with reduced content of cluster, whereas the first embossing roller **103**, the second embossing roller **104**, the adapted-shape scrappers **1202** and **1203**, the air-depression cleaning systems **108** and **109**, as well as the removed debris **306** are showed in **Figure 18**. A magnified view from a zone **110** of the sheet of substrate **101** prior to embossing using the embossing system **1801** schematically depicts inhomogeneities of substrate thickness values and substrate clusters, while a further magnified view of a zone **111** from the embossed sheet of substrate **100** schematically shows the embossed sheet substrate with the controlled thickness value and with the reduced content of cluster. In a further preferred embodiment, the embossed sheet of substrate **100** with controlled thickness and with reduced content of clusters is fed into a second embossing system **1802** that contains a third **1803** and a fourth **1804** embossing roller, configured to further emboss at least an aerodynamic profile to obtain the embossed sheet of substrate **1805**, the embossed aerodynamic profiles being configured to modify in a determined manner flow properties for a

gas flow passing through the embossed aerodynamic profiles by creating a gas flow turbulence. A further magnified view from a zone **1806** of the further embossed sheet of substrate **1805** illustrates an example embossing obtained with the embossing set-up **1802** configured to emboss at least an aerodynamic profile, according to a preferred embodiment of the invention. As an option, the production line may comprise a bobbin dispensing device **1800** configured to carry a bobbin with a web of sheet of substrate **101** and unwind it out towards the embossing set-up **1801**.

Figure 19 illustrates a further preferred embodiment of the system as in **Figure 18** with additional debris removal systems according to the invention. **Figure 19** illustrates a further preferred embodiment of the embossing set-up **1801** according to the invention as a part of an online production process, wherein the embossing set-up **1801** is part of an online production line for manufacturing a filter element of length L (filter element and length not represented). The online production line further comprises for example a compacting device **1809** comprising a funnel **1807** into which the embossed sheet of substrate **1902** is fed, folded and formed into a filter rod **1904** output by the compacting device **1809**. Hence the embossed sheet of substrate **1902** is compacted with the funnel **1807**. The filter rod **1904** may be pulled by means of a pulling jig **1810** to a further process step **1811** of cutting. The production line contains the embossing system **1801**, according to the invention, to produce an embossed sheet of substrate with controlled thickness value and reduced content of clusters, whereas the first embossing roller **103**, the second embossing roller **104**, the adapted-shape scrappers **1202** and **1203**, the air-depression cleaning systems **108** and **109**, as well as the removed debris **306** are illustrated in **Figure 19**. In a preferred embodiment, the embossed sheet of substrate **100** with controlled thickness value and with reduced content of clusters passes through at least one of the additional debris removal systems **1900** and **1901**, whereas the air-depression cleaning systems **503** and **504**, as well as the additional removed debris **305** are equally illustrated in **Figure 19**. The so-conditioned embossed sheet of substrate **507** with controlled thickness value and with substantially reduced content of clusters is fed into the second embossing system **1802** that contains the third **1803** and the fourth **1804** embossing rollers, configured to emboss at least an aerodynamic profile on the embossed sheet of substrate **1902**, the embossed aerodynamic profiles being configured to modify in a determined manner flow properties for a gas flow passing through the embossed aerodynamic profiles by creating a gas flow turbulence. As an option, the production line may comprise the bobbin dispensing device **1800** configured to carry the bobbin with the web of sheet of substrate **101** and unwind it out towards the embossing set-up **1801**.

Figure 20 illustrates a further example of an embossed sheet of substrate further embossed according to the invention, bearing aerodynamic profiles. More precisely, **Figure 20** contains a detailed top view from a zone **1903** (as in **Figure 19**) of a sheet of substrate embossed according to the invention, with controlled thickness value and with substantially reduced content of clusters, which shows recessed **2001** and protruded **2002** embossed radial features **2003**,

substantially parallel and separated by a distance I , whereas each embossed radial feature **2003** defines a plurality of enclosures **2006**, which are longitudinally distributed along the corresponding embossed radial feature and separated by a distance p . **Figure 20** further includes a cross-sectional view **2007** from a zone of a nip between the embossing rollers **1803** and **1804** used to obtain the embossed the sheet of substrate **1903**, which corresponds to a symbolic line **2004** along the embossed sheet of substrate, and which also illustrates a height $h1$ of an embossed protrusion feature, as well as a nip thickness value **2105**.

Figure 21 schematically illustrates an obtaining of filtering elements using an embossed sheet of substrate as resulting from the invention. Starting from the process step of cutting **1811**, **Figure 21** illustrates under reference **2100** a cutting process that involves cutting the filter rod **1808** into individual pieces of filter elements **2101** each having the length L , and as an example, cut as two twin-filter elements by means of a cutting device **2102**. **Figure 21** further illustrates a magnified photograph view **2103** at an extremity of one of the filter elements **2101**, in which the embossed sheet of substrate **1805** is folded and compacted to fit in a cylindrical wrapper **2104**, represented as a section of the cylindrical wrapper **2104**. A detailed view **2105** of a part of the section **2103**, in which the view is slightly from an angle, schematically illustrates how the embossed sheet of substrate **1805** is folded and packed in a manner of an accordion. In the view **2105** a substrate thickness **2106** is represented to be the same all over, and while this may be desired to be in this manner, there may also be embossed features (not represented) in which the substrate thickness may vary according to the embossed features.

Figure 22 schematically illustrates how a filtering element, in this case a cigarette filter, may be mounted to a tobacco containing section in order to obtain a cigarette according to prior art. More precisely, **Figure 22** schematically illustrates how a cigarette filter - type filtering element **2101**, in a preferred embodiment initially obtained as two twin-filters, may be mounted to a tobacco containing section **2201** in order to obtain a cigarette **2202** according to prior art. Part **(A)** shows two twin-filter elements **2101**, part **(B)** shows the two twin-filter elements **2101** positioned between tobacco containing sections **2201**, and a filter paper **2200** being wound and glued around the two filter elements **2101** and partly over a part of each tobacco containing section **2201**, resulting in two twin-cigarettes **2202** shown in part **(C)**. Part **(D)** shows one of cigarettes **2202** obtained after cutting the two twin-cigarettes in a middle **2203** thereof.

Figure 23 schematically illustrates a structure of an inhalable drug delivery device **2300** in parts **(A)** and **(B)**, according to the prior art. Part **(A)** depicts a delivery system comprising a drug-containing component **2301** and a filtering element **2302** fabricated using a sheet of substrate embossed according to the invention. Part **(B)** depicts an inhalable drug delivery system comprising the drug-containing component **2301**, a cooling component **2303**, and of the filtering element **2302** fabricated using a sheet of substrate embossed according to the invention.

Figure 24 contains a flowchart illustrating an example embodiment of a method for manufacturing an embossed sheet of substrate **2409** according to the invention. The method is configured to produce a controlled thickness value of the embossed sheet of substrate and to reduce a content of clusters present in the substrate prior to embossing. The method comprises steps of

- providing a sheet of substrate **2400** comprising the first material **200**, the sheet of substrate having an average starting thickness;
- providing an embossing roller system **2401** comprising at least the first and the second embossing roller, having respectively the first radial profile and the corresponding second radial profile congruent to the first radial profile, the first radial profile comprising embossing structures protruding from or recessed in a base surface of the first embossing roller, and forming radially oriented ridges and grooves respectively;
- inserting the sheet of substrate in the nip **2402** formed between the first and the second embossing rollers;
- adjusting an embossing pressure **2403** between the first and the second embossing roller to obtain the determined nip value of the nip, smaller than the average starting thickness;
- embossing the sheet of substrate **2404**, thereby obtaining the controlled thickness value of the embossed sheet of substrate smaller than the average starting thickness;
- compressing **2405** in the nip at least the first type of cluster comprising the first material inside the embossed sheet of substrate;
- processing **2406** at least the second type of cluster made of a second material different from the first material in any one of the following manners:
 - compressing and maintaining the at least one second type of cluster in the embossed sheet of substrate;
 - extracting the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure, which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to a surface of the embossed sheet of substrate;
 - extracting the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure, which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to any one of the base surfaces and the embossing structures of the first and second embossing rollers;
- detaching the debris from the base surfaces and the embossing structures **2407** by means of a roller cleaning tool; and
- removing the detached debris from the embossing roller system **2408** by means of an air-depression cleaning system **108**, **109**.

Nip value, controlled thickness and cluster size

In one example of embodiment, a sheet of substrate used to produce a cigarette filter, having a grammage of 62 gsm, exhibits thickness values between 360 μm and 480 μm (i.e., a variation range of 120 μm) and an average thickness value of 410 μm was treated. For this substrate, clusters of lateral expansions in a range between 0.5 mm and 5.0 mm were evidenced, whereas the substrate thickness values measured at the cluster spots reached values up to 580 μm . In this example, embossing to obtain the controlled thickness and a reduced content of clusters was carried out with nip values of 100 μm and a linear force of 13,6 kN/m. As a result of the embossing, a variation range of 20 μm (instead of initially 120 μm) was found for the measured substrate thickness values and no protruding clusters were observed.

Integration of the embossing roller system

While carrying out the embossing process according to the invention care should be taken that both the non-embossed sheet of substrate **101** and the embossed sheet of substrate **100** shall be strained and stay under a certain substrate tension. This is common practice in the field of embossing. In one example of realisation of the invention, embossing trials carried out according to the invention on different types of sheets of substrates, both woven and non-woven, showed a range between 1 N and 10 N for an optimal substrate tension for both substrates **100**, **101**. The aforementioned trials also pointed out that, in a preferred embodiment, the substrate tensions for the sheets of substrate **100** and **101** shall be varied independently, as for instance a thinner sheet of substrate requires a lower substrate tension after **100** than before **101** the embossing roller system. Furthermore, under too low substrate tensions (e.g., <1 N) in the non-embossed sheet of substrate **101**, this may become loose and form crinkles in the nip between the embossing rollers, which will have a negative effect on the controlled thickness supposed to be obtained through embossing, whereas too high substrate tensions (e.g. >10 N) in the embossed sheet of substrate **100** might generate its rupture and interrupt the embossing process.

Claims

1. Method for manufacturing an embossed sheet of substrate (100), the method being configured to produce a controlled thickness value of the embossed sheet of substrate and to reduce a content of clusters present in the non-embossed substrate (101), the method comprising steps of

providing a sheet of substrate (101) comprising a first material (200), the sheet of substrate having an average starting thickness;

providing an embossing roller system (102) comprising at least a first and a second embossing roller (103, 104), having respectively a first radial profile and a corresponding second radial profile congruent to the first radial profile, the first radial profile comprising embossing structures protruding from or recessed in a base surface of the first embossing roller, and forming radially oriented ridges and grooves respectively;

inserting the sheet of substrate in a nip (105) formed between the first and the second embossing roller;

adjusting an embossing pressure (P) between the first and the second embossing roller to obtain a determined nip value of the nip, smaller than the average starting thickness;

embossing the sheet of substrate;

thereby obtaining the controlled thickness value of the embossed sheet of substrate smaller than the average starting thickness;

compressing in the nip at least a first type of cluster comprising the first material inside the embossed sheet of substrate;

processing at least a second type of cluster made of a second material different from the first material in any one of the following manners:

compressing and maintaining the at least one second type of cluster in the embossed sheet of substrate;

extracting the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure (P), which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to a surface of the embossed sheet of substrate;

extracting the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure (P), which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to any one of the base surfaces and the embossing structures of the first and the second embossing rollers;

the method further comprising:

detaching the debris from the base surfaces and the embossing structures by means of a roller cleaning tool (106, 107); and

removing the detached debris from the embossing roller system (102) by means of an air-depression cleaning system (108, 109).

2. The method according to claim 1, further comprising after embossing the sheet of substrate:

leading the embossed sheet of substrate through at least an additional debris removal system (505, 506), thereby

deflecting the embossed sheet of substrate on a removal tool (501, 502) of the additional debris removal system, configured to detach debris (305) adhering to the surface of the embossed sheet of substrate (100); and

removing the detached debris (305) from the debris removal system by means of an additional air-depression cleaning system (503, 504) corresponding to the additional debris removal system.

3. The method according to claim 2, wherein the removal tool to detach debris (305) adhering to the surface of the embossed sheet of substrate (100) comprises any one of the following items of a list comprising:

a cylinder comprising a roughened surface configured to be in contact with the embossed sheet of substrate;

a curved roughened surface configured to be in contact with the embossed sheet of substrate;

a blade comprising an edge configured to be in contact with the embossed sheet of substrate;

an ultrasonic wave generator configured to project an ultrasonic beam towards the embossed sheet of substrate.

4. The method according to any one of claims 1 to 3, wherein
the roller cleaning tool comprises at least a scrapper (1202, 1203) for each of the embossing rollers, each scrapper comprising an edge configured to be presented towards the roller surface of the corresponding embossing roller, and having a shape fitting congruently in the corresponding radial profile of the embossing roller, and configured in such a way that the debris (306) adhering to any one of the base surface and the embossing structures of the roller surface is removed from the roller surface while the embossing roller rotates.
5. The method according to any one of claims 1 to 4, wherein the step of providing the embossing roller system comprises mounting each of the first and the second embossing rollers in a corresponding quick exchange fixture (1102, 1103), whereby each of the quick exchange fixtures is removably mounted in a frame (1101).
6. The method according to any one of claims 1 to 4, wherein the step of providing the embossing roller system comprises mounting and adjusting the first and the second embossing rollers in a quick exchange cassette (1104), whereby the quick exchange is removably mounted in a frame (1105).
7. The method according to any one of the claims 1 to 6, further comprising
providing a further embossing roller system comprising a third (1803) and a fourth (1804) embossing roller, with further embossing features configured for embossing at least an aerodynamic profile on the embossed sheet of substrate, the embossed aerodynamic profiles being configured to modify in a determined manner flow properties for a gas flow passing through the embossed aerodynamic profiles by creating a gas flow turbulence;
inserting the embossed sheet of substrate in a further nip formed between the third and the fourth embossing rollers;
further embossing the embossed sheet of substrate.

8. The method according to claim 7, wherein
the further embossing roller system is part of a production chain for manufacturing from
the sheet of substrate a filtering element configured for an inhalable drug delivery
device, and for filtering a mainstream gas flow passing through the filtering
element.
9. The method according to any one of claims 7 to 8, wherein the step of providing the
further embossing roller system comprises mounting each of the third and fourth
embossing roller in a corresponding quick exchange fixture, whereby each of the quick
exchange fixtures is removably mounted in a frame.
10. The method according to any one of claims 7 to 8, wherein the step of providing the
further embossing roller system comprises mounting each of the third and fourth
embossing roller mounting and adjusting the first embossing roller and the second
embossing roller in a quick exchange cassette, whereby the quick exchange is removably
mounted in a frame.
11. The method according to any one of claims 1 to 6, wherein each of the radially oriented
ridges and grooves comprises two contiguous radially directed flanks that define an angle
between two contiguous flanks of the radially ridges and grooves that has a value
between 75° and 140°.
12. The method according to any one of claims 1 to 6, wherein the radially oriented ridges
and grooves are described by a top-of-ridge to bottom-of-groove height value situated in
a range 0.1 mm and 1.0 mm.
13. The method according to any one of claims 1 to 6, wherein the radially oriented ridges
and grooves are arranged in a parallel, periodic manner which is described by a
dimensional spacing of at least 0.5 mm between two adjacent ridges and grooves.
14. The method according to any one of claims 1 to 6, wherein the first and the second
embossing rollers are driven and self-synchronized by means of the radial embossing

features engaged into each other by applying an embossing pressure (P) between the rollers.

15. The method according to any one of claims 1 to 6, wherein the first and the second embossing rollers are driven and synchronized by any means from a list of synchronization means comprising toothed-wheels gears, helicoidal gears, servomotors.
16. The method according to any one of the preceding claims, wherein the non-embossed sheet of substrate has a grammage in a range between 10 gsm and 150 gsm and a starting average thickness value in a range between 0.02 mm and 1.0 mm.
17. The method according to any one of the preceding claims, wherein the sheet of substrate comprises any material from a list comprising paper, woven cellulose-based material, non-woven cellulose-based material, natural fibrous material, synthetic fibrous material, porous material, and mixtures thereof.
18. A system for manufacturing an embossed sheet of substrate (100), the system being configured to produce a controlled thickness value of the embossed sheet of substrate and to reduce a content of clusters present in the non-embossed substrate (101), the system comprising

an embossing roller system (102) comprising at least a first and a second embossing roller (103, 104), having respectively a first radial profile and a corresponding second radial profile congruent to the first radial profile, the first radial profile comprising embossing structures protruding from or recessed in a base surface of the first embossing roller, and forming radially oriented ridges and grooves respectively;

the embossing roller system further comprising a nip (105) formed between the first and the second embossing roller and configured for inserting therein a sheet of substrate (101) comprising a first material (200), the sheet of substrate having an average starting thickness;

pressure adjusting means configured to adjust an embossing pressure (P) between the first and the second embossing roller and obtain a determined nip value of the nip, smaller than the average starting thickness;

whereby an embossing of the sheet of substrate enables to

obtain the controlled thickness value of the embossed sheet of substrate smaller than the average starting thickness;

compress at least a first type of cluster comprising the first material inside the embossed sheet of substrate;

process at least a second type of cluster made of a second material different from the first material in any one of the following manners:

compress and maintain the at least one second type of cluster in the embossed sheet of substrate;

extract the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure (P), which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to a surface of the embossed sheet of substrate;

extract the at least one second type of cluster as debris from the sheet of substrate by means of the embossing pressure (P), which causes the at least one second type of cluster to emerge from the embossed sheet of substrate and adhere as debris to any one of the base surfaces and the embossing structures of the first and second embossing rollers;

the system further comprising:

a roller cleaning tool (106, 107) configured to detach the debris from the base surfaces and the embossing structures; and

an air-depression cleaning system (108, 109) configured to remove the detached debris from the embossing roller system (102).

19. The system according to claim 18, further comprising

at least an additional debris removal system (505, 506), configured to further lead through the embossed sheet of substrate,

a removal tool in the additional debris removal system configured to deflect the embossed sheet of substrate, and configured to detach debris (305) adhering to the surface of the embossed sheet of substrate (100); and

an additional air-depression cleaning system (503, 504) corresponding to the additional debris removal system, configured for removing the detached debris (305) from the debris removal system by means of an additional air-depression cleaning system (503, 504).

20. The system according to claim 19, wherein the removal tool to detach debris (305) adhering to the surface of the embossed sheet of substrate (100) comprises any one of the following items of a list comprising:
 - a cylinder comprising a roughened surface configured to be in contact with the embossed sheet of substrate;
 - a curved roughened surface configured to be in contact with the embossed sheet of substrate;
 - a blade comprising an edge configured to be in contact with the embossed sheet of substrate;
 - an ultrasonic wave generator configured to project an ultrasonic beam towards the embossed sheet of substrate.
21. The system according to any one of claims 18 to 20, wherein
 - the roller cleaning tool comprises at least a scrapper (1202, 1203) for each of the embossing rollers, each scrapper comprising an edge configured to be presented towards the roller surface of the corresponding embossing roller, and having a shape fitting congruently in the corresponding radial profile of the embossing roller, and configured in such a way that the debris (302) adhering to any one of the base surface and the embossing structures of the roller surface is removed from the roller surface while the embossing roller rotates.
22. The system according to any one of claims 18 to 21, further comprising at least two quick exchange fixtures (1102, 1103), respectively configured to mount each of the first and the second embossing rollers, whereby each of the quick exchange fixtures is removably mounted in a frame (1101).
23. The system according to any one of claims 18 to 21, further comprising a quick exchange cassette (1104) configured to comprise the first and the second embossing rollers

adjusted inside the quick exchange cassette, and the quick exchange cassette is removably mounted in a frame (1105).

24. The system according to any one of the claims 18 to 23, further comprising
- a further embossing roller system comprising a third (1803) and a fourth (1804) embossing roller, with further embossing features configured for embossing at least an aerodynamic profile on the embossed sheet of substrate, the embossed aerodynamic profiles being configured to modify in a determined manner flow properties for a gas flow passing through the embossed aerodynamic profiles by creating a gas flow turbulence;
- the further embossing roller system further comprising a further nip formed between the third and the fourth embossing rollers, and configured for inserting therein the embossed sheet of substrate.
25. The system according to claim 24, wherein
- the further embossing roller system is part of a production chain for manufacturing from the sheet of substrate a filtering element configured for an inhalable drug delivery device, and for filtering a mainstream gas flow passing through the filtering element.
26. The system according to any one of claims 24 to 25, further comprising at least two further quick exchange fixtures, respectively configured to mount each one of the third and fourth embossing rollers, whereby each of the further quick exchange fixture is removably mounted in a frame.
27. The system according any one of claims 24 to 25, further comprising a further quick exchange cassette configured to comprise the third embossing roller and the fourth embossing roller adjusted inside the further quick exchange cassette, and the further quick exchange cassette is removably mounted in a frame.
28. The system according to any one of claims 18 to 23, wherein each of the radially oriented ridges and grooves comprises two contiguous radially directed flanks that define an angle

between two contiguous flanks of the radially ridges and grooves that has a value between 75° and 140°.

29. The system according to any one of claims 18 to 23, wherein the radially oriented ridges and grooves are described by a top-of-ridge to bottom-of-groove height value situated in a range 0.1 mm and 1.0 mm.
30. The system according to any one of claims 18 to 23, wherein the radially oriented ridges and grooves are arranged in a parallel, periodic manner which is described by a dimensional spacing of at least 0.5 mm between two adjacent ridges and grooves.
31. The system according to any one of claims 18 to 23, wherein the first and the second embossing rollers are configured to be driven and self-synchronized by means of the radial embossing features engaged into each other by applying an embossing pressure (P) between the rollers.
32. The system according to any one of claims 18 to 23, wherein the first and the second embossing rollers are driven and synchronized by any means from a list of synchronization means comprising toothed-wheels gears, helicoidal gears, servomotors.
33. The system according to any one of the claims 18 to 32, wherein the non-embossed sheet of substrate has a grammage in a range between 10 gsm and 150 gsm and a starting average thickness value in a range between 0.02 mm and 1.0 mm.
34. The system according to any one of the claims 18 to 33, wherein the sheet of substrate comprises any material from a list comprising paper, woven cellulose-based material, non-woven cellulose-based material, natural fibrous material, synthetic fibrous material, porous material, and mixtures thereof.