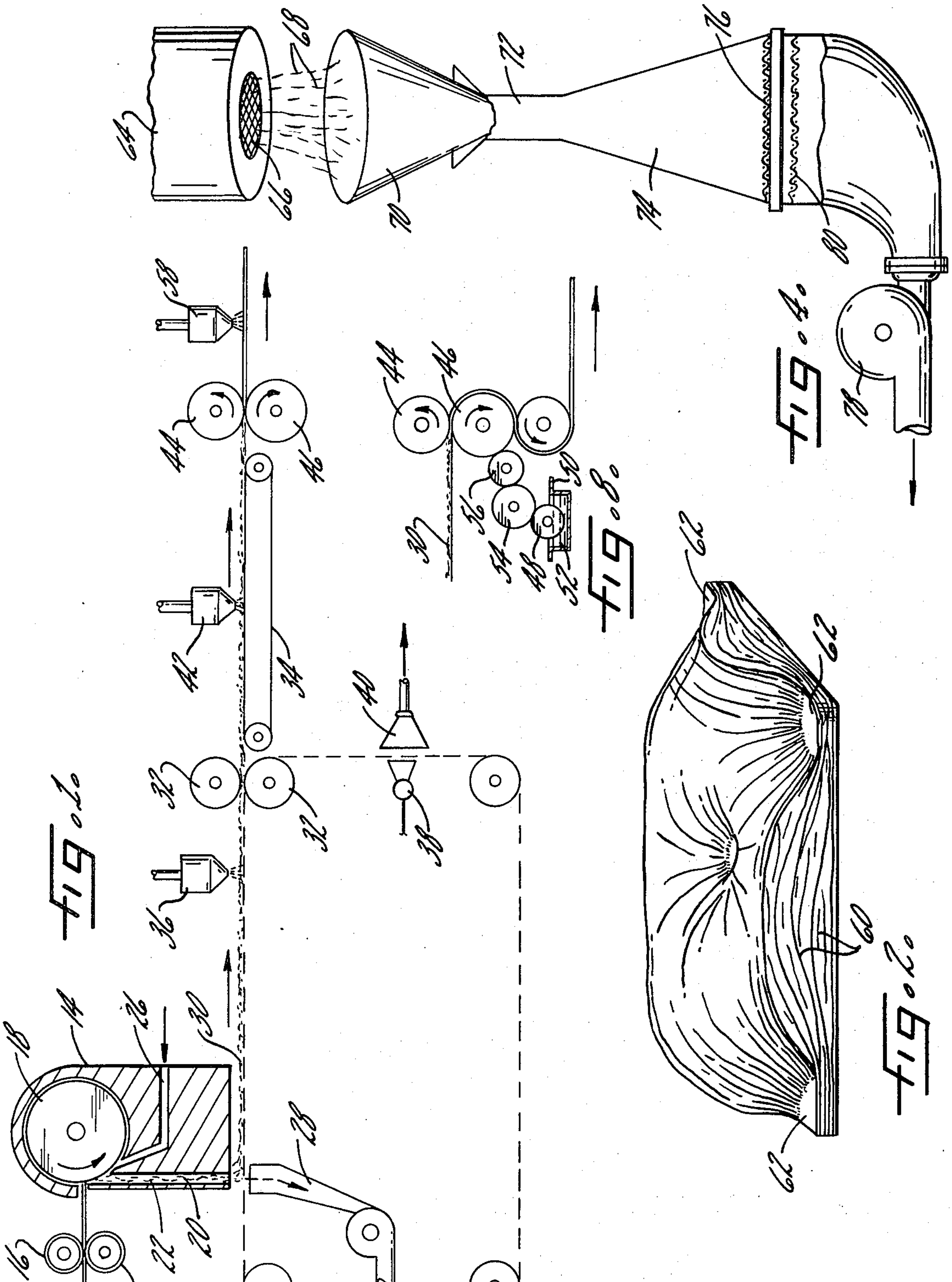
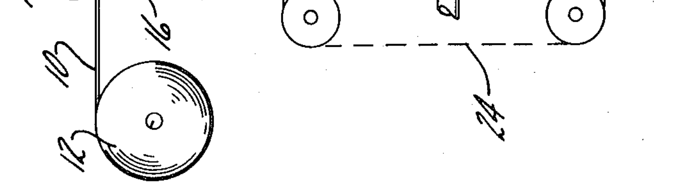
Sept. 19, 1972 C. E. DUNNING 3,692,622

AIR FORMED WEBS OF BONDED PULP FIBERS

Filed Dec. 4, 1969 3 Sheets-Sheet 1





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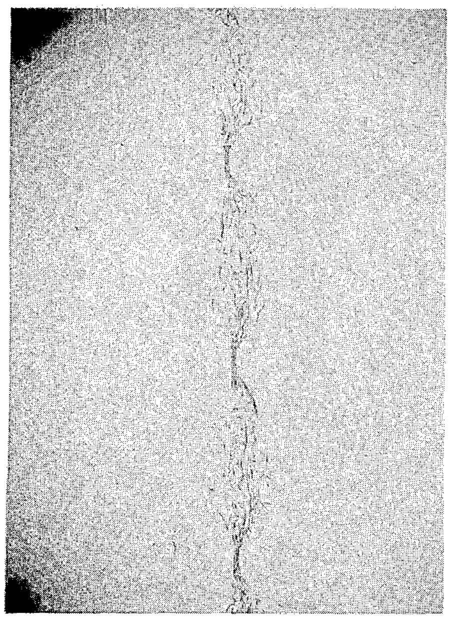

FIG. 3

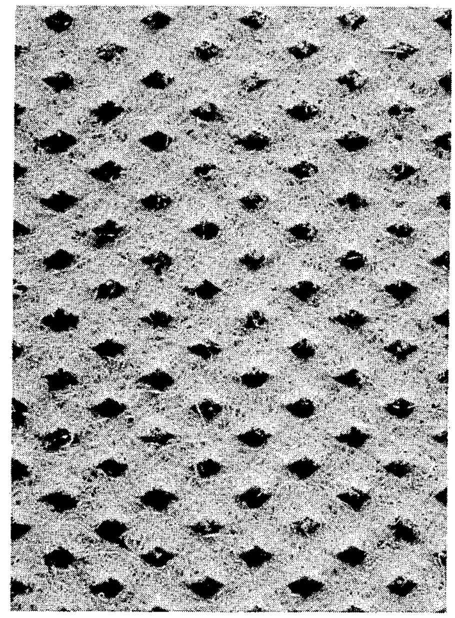

FIG. 5

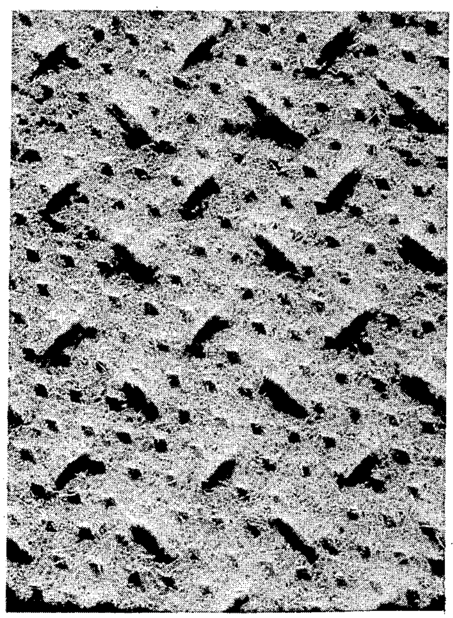

FIG. 6

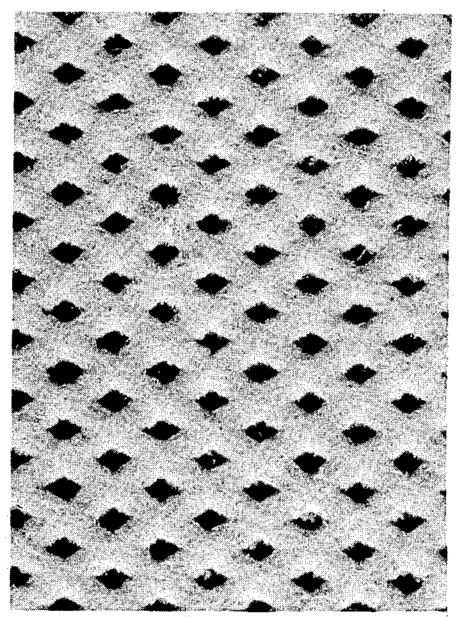

FIG. 7

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AIR FORMED WEBS OF BONDED PULP FIBERS

Filed Dec. 4, 1969 3 Sheets-Sheet 3

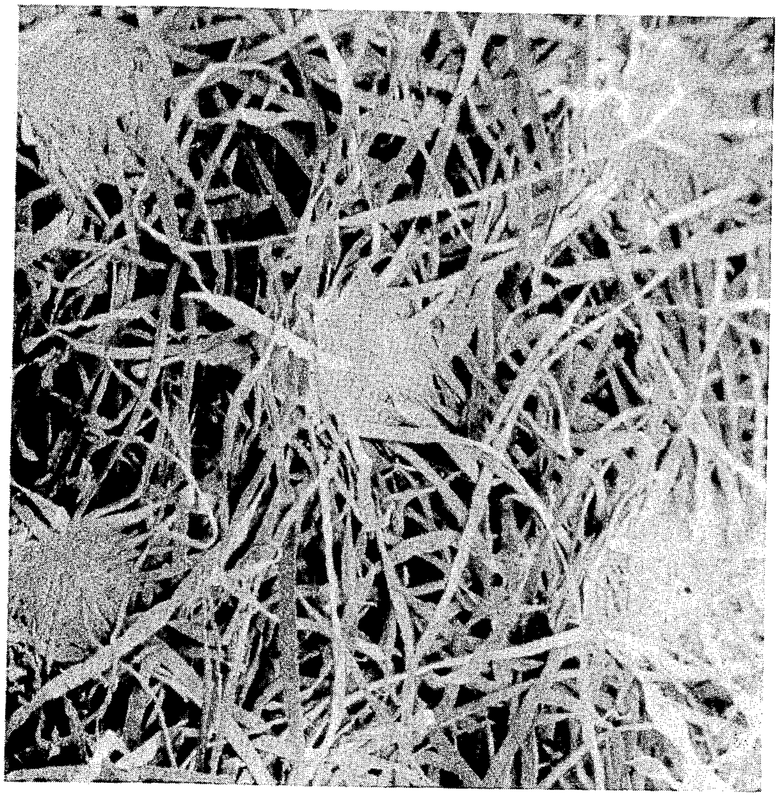

FIG. 9

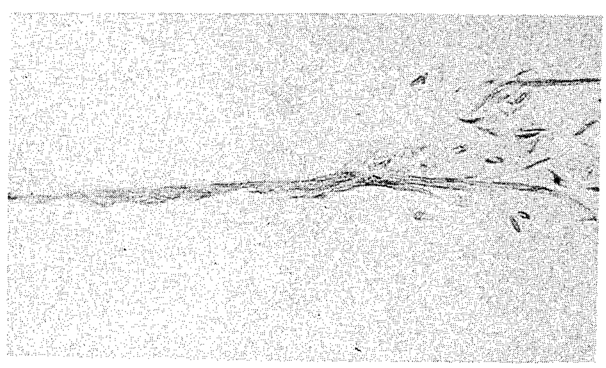

FIG. 10

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3,692,622
AIR FORMED WEBS OF BONDED PULP FIBERS
Charles E. Dunning, Neenah, Wis., assignor to Kimberly-Clark Corporation, Neenah, Wis.
Continuation-in-part of abandoned application Ser. No. 783,877, Dec. 16, 1968. This application Dec. 4, 1969, Ser. No. 882,257
Int. Cl. D21h 5/26; D04h 1/04
U.S. Cl. 161—124 10 Claims

ABSTRACT OF THE DISCLOSURE

Paper products useful as sanitary wipes and towelling are prepared by air laying a web of wood pulp fibers and binding the web by passing it through a nip formed between a smooth roll and a patterned roll. Prior to bonding, the moisture content of the web is adjusted to 6–35%. The products so prepared, have a very desirable combination of strength, absorbency, and tactile properties compared with conventional products. The products need not be creped to develop the improved characteristics.

This application is a continuation-in-part of my copending application Ser. No. 783,877, filed Dec. 16, 1968, now abandoned.

DESCRIPTION OF THE INVENTION

This invention relates to paper products and, more particularly, to paper products useful in sanitary wipe and towelling applications which are characterized by a desirable combination of strength, absorbency, and tactile properties.

Conventionally, disposable tissue and towel products have been formed on paper-making equipment by water laying a wood pulp fibrous sheet and, thereafter, removing the water either by drying or a combination of pressing and drying. During water removal, strong capillary surface tension forces develop fibers and a degree of overall bonding inevitably results. Such is true even in the absence of extensive pressing. Due to this overall bonding phenomenon, sheets prepared by water laying methods inherently possess very unfavorable tactile properties (e.g., harshness, stiffness, low bulk, and poor overall softness) and absorbency. Consequently, in order to enhance these latter properties, water laid sheets are creped, i.e. the paper sheet is scraped from a drier roll with a doctor blade. Creping artificially improves the tactile and absorbency properties by disrupting the excessive fiber bonding.

However, creping in order to improve the aforementioned properties has several limitations. First of all, creping is only effective on low, e.g., less than about 15 lb., basis weight webs. Conventionally prepared creped webs with higher basis weights are quite stiff and are generally unsatisfactory for uses such as quality facial tissues. As a consequence of this, it is conventional practice to employ two piles of creped low basis weight webs for such uses. Only by doing this can a sufficiently bulky product with acceptable softness be prepared.

A second limitation associated with creping is that even with respect to low basis weight materials, the detrimental effects of the initial overall bonding are not completely offset. In a water laid method, there is preferential fiber orientation in the machine direction. As a result, the strength in this direction is always higher than in the cross direction. Consequently, creped products, with acceptable cross direction strength still have excessive machine direction strength. Due to this excessive strength, which is a necessary result of achieving adequate cross direction strength, the attainment of optimum tactile properties is prevented. Thus, even low basis weight creped webs do not have optimum tactile properties.

Sanford (U.S. Pat. 3,301,746) proposes to improve the tactile properties of a water laid sheet by thermally predrying a sheet to fiber consistency substantially in excess of that normally applied to the drier surface of a paper machine. The partially dried sheet is then imprinted with a knuckle pattern of an imprinting fabric and, thereafter, dried without disturbing the imprinted knuckle pattern bonds. While this method may somewhat improve the softness, bulk, and absorbency of the resulting sheet the spaces between the knuckle bonds are still appreciably compacted by the surface tension forces present during water removal, and the fibers substantially bonded therein. Creping is still essential in order to realize maximum advantage of the proposed process, and for many uses, two plies are still necessary.

As is apparent from the above discussion, conventional water laying paper-making methods involve the inefficient aspect of initially "overbonding," and then having to crepe to "debond." Additionally, the necessity of removing large quantities of water is disadvantageous, particularly in view of the associated water pollution problem. Moreover, products with acceptable strength and improved tactile and absorbency properties over those presently available would be very desirable, especially if they could be used as single plies.

Air forming of wood pulp fibrous webs has been carried out for many years. However, the resulting webs have only been used for applications where either little strength is required, such as for absorbent products (e.g. pads), or applications where a certain minimum strength is required but the tactile and absorbency properties are unimportant (e.g. various specialty papers). U.S. Pats, 2,447,161 and 2,810,940 and British patent specification 1,088,991 illustrate air forming techniques for such applications. Indeed, heretofore, it has not been believed that air forming techniques could be advantageously used in preparing paper products useful for sanitary wipes and towelling.

It is an object of the present invention to provide aesthetically pleasing paper-like webs having a desirable combination of strength, absorbency, and tactile properties. A further object is to provide such webs with acceptable strength and improved absorbency and tactile properties compared with conventional products. In this connection, a related object is to provide a paper-like web that may be advantageously employed as a substitute for conventional wipes and towelling. Furthermore, it is an object to provide webs with the aforementioned characteristics which can be used as a single ply.

Another object of the present invention is to provide an economical and efficient process for air forming webs having the hereinbefore described properties. A further object is to provide a process for forming products of the above-described type wherein the properties of the resulting product may be easily tailor made to the end use contemplated. A still further object is to provide a process for forming products of the above-described type wherein the desirable combination of properties is achieved without creping.

Other objects and advantages will become apparent as the following description proceeds, taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic view illustrating apparatus that is capable of forming the fibrous webs of the present invention on a continuous or semi-continuous basis;

FIG. 2 is a schematic view of a portion of a single-ply web and showing its fluffy mound-like configuration;

FIG. 3 is a photomicrograph of a portion of the cross section of a web such as is illustrated in FIG. 2, taken through a line of bonds;

FIG. 4 is a schematic view illustrating apparatus that can be used to carry out the novel process of the present invention on a batch scale;

FIG. 5 is a photomicrograph of a portion of a single-ply web which can be employed for towelling;

FIG. 6 is a photomicrograph of a portion of a two-ply web and which can be used as towelling;

FIG. 7 is a photomicrograph of a portion of a single-ply web and which can be utilized as a facial wipe;

FIG. 8 is a schematic view illustrating apparatus that can be used in applying adhesive during the present process;

FIG. 9 is scanning electron micrograph of a web of the present invention; and

FIG. 10 is a photomicrograph of a cross section of a web of the present invention;

While the invention is susceptible of various modifications and alternative constructions, there is shown in the drawings and will herein be described in detail the preferred embodiments. It is to be understood, however, that it is not intended to limit the invention to the specific forms disclosed. On the contrary, it is intended to cover all modifications and alternative constructions falling within the spirit and scope of the inventions as expressed in the appended claims.

Briefly, a preferred example of the product constructed according to the present invention is illustrated in FIG. 2. As such, it comprises a soft, absorbent web having a basis weight of 5–50 lbs./2880 sq. ft. prepared by forming a continuum of substantially unbonded wood pulp fibers and, thereafter, uniting the fibers into a coherent structure by bonding the fibers together at regularly patterned areas of the continuum. The bonded areas occupy 5–40% of the web area, and are spaced less than about the average fiber length apart. The thickness of the continuum is at least 2.5 times thicker than the bonded areas.

FIG. 1 sets forth a process aspect of the present invention, and illustrates how the product shown in FIG. 2 can be prepared on a continuous or semi-continuous basis. Substantially dry wood pulp sheet **10** is unwound from a roll **12** and forwarded to a picking chamer **1** by feed rolls **16** powered by means not shown. To separate the pulp sheet into its individual fibers, a conventional picker roll **18** having teeth around its circumference is employed. The picker roll **18** separates the pulp sheet into its individual fibers **20** which are conveyed through the forming duct **22** to the forminous moving wire **24**. Air from the source **26** in combination with the vacuum box **28** creates a downwardly moving stream of air which assists in collecting the web **30** on the moving wire **24**.

After formation, the web is passed through calender rolls **32** to lightly compact the web and give it sufficient integrity to be transferred to the belt **34**. A light water spray can be applied from nozzle **36** in order to counteract static attraction between the web and the wire. An air shower **38** and vacuum box **40** serve to clean loose fibers from the wire **24** and thus prevent fiber build-up.

After transfer to the belt **34**, the moisture content of the web is adjusted to 6–35% by a water spray **42** and, thereafter, the web is bonded by passing it through the nip between the smooth hard roll **44** and the patterned steel roll **46**. Subsequently, the bonded web can be dried and rolled up or otherwise stored for end use applications there being no necessity that it be creped.

In accomplishing the above-described process, there are several important aspects which directly influence the tactile, absorbency, and strength characteristics of the resultant product. First of all, prior to bonding, it is important that the fibers in the web be essentially randomly oriented and substantially unbonded. While customary air forming techniques can be used in preparing a web having such characteristics, the forming duct illustrated in FIG. 1 is particularly efficient in obtaining an especially suitable web. The illustrated duct has a width approximately equal to the height of the picker teeth, and is positioned so as to tangentially receive the fibers as they leave the picker. By using a duct with such a width, fiber velocity can be maintained essentially constant throughout the length of the duct. Webs formed in this manner have exceptionally good cross-width uniformity and are substantially free of fiber floccing. The appropriate size of the forming duct and its arrangement with respect to the picker and wire are described in detail in Appel and Sanford U.S. Pat. 3,606,175 entitled "Picker for Divellicating Pulp." As hereinafter described, the random fiber orientation in the present webs contributes significantly to the fact that acceptable strength characteristics can be achieved along with desirable tactile properties and absorbency.

A second important aspect of the process concerns the moisture content of the web prior to bonding. It has been found that the web should contain about 6–35% moisture (percent of the humidified web weight) prior to bonding. Higher moisture content, e.g., to an extent where moisture fills in void volume, detrimentally affects the tactile and absorbency characteristics of the finished product presumably due to increased web compaction and bonding in nominally uncompacted spots. On the other hand, at lower moisture contents, it is difficult to achieve adequate strength characteristics. A moisture content prior to bonding of 10–30% is preferred.

The manner in which the web is bonded is a third important process feature. In order to produce a product with the sought-after properties, it has been found that the area, the pressure, and the spacing of bonding is important. Referring again to FIG. 1, the steel roll **46** should have an embossing pattern such that the total bonded area in the resultant web occupies about 5–40%, generally 8–20%, of the web area. As with the above-described moisture content, higher bonded areas detrimentally affect absorbency and tactile properties, while insufficient strength is present in webs with lower bond areas. The most useful total bonded area for a particular web is related to the weight of the web. For webs with basis weights of less than about 20 lbs. per 2880 sq. ft. e.g., 5–20 lbs., bond areas of 10–40% are most useful while areas of 10–20% are particularly preferred. On the other hand, for webs with basis weights greater than 20 lbs., e.g., 20–50 lbs., bond areas of 5–25%, and particularly 8–15%, are generally most satisfactory.

Aside from total bonded area, bond frequency is also important. In order to assure adequate strength characteristics, the spacing between bonded areas should be less than about the average length of the wood pulp fibers making up the web. Furthermore, in order to enhance web strength uniformity, a regularly repeating bonding pattern is preferred. With total bond areas of 5–40%, individual bond areas having a frequency of10–40 per inch across both dimensions of the web are useful. A frequency of 15–35 areas per inch is generally preferred. The appropriate area of an individual bond can be determined from the total bonded area and the individual bond area frequency as above discussed.

During bonding, there must be sufficient pressure to cause the fibers in the individual areas to form hydrogen bonds. As used herein, the term "hydrogen bond" describes those bonds customarily present in self-bonded conventional paper products. As such, they are believed to be secondary valence bonds between OH groups and H atoms in contacting fibers. FIG. 9 illustrates how the bond areas in the web prepared according to the following Example II appear under a scanning electron microscope at 100× magnification. The bond areas can be seen to be composed of highly compacted fibers.

In order to achieve sufficient bonding in the above described process, the pressure exerted on an individual bond area should be at least 2,000 p.s.i. To a large extent, the maximum pressure is determined by the yield point of the respective nip rolls, although, for practical purposes, it will generally not exceed 30,000 p.s.i. In this respect, it is frequently desirable to use, in combination with the patterned roll, a resilient, e.g., nylon, smooth roll. The use of such a roll diminishes the wear on the patterned roll.

The configuration of the raised portions on the patterned roll is not thought to be particularly critical although, to a limited extent, the configuration can influence directional strength characteristics. However, in order to avoid significant compaction of the web in areas other than those to be specifically bonded, it is desirable that the sides of the raised portions be comparatively steep. With respect to the height of the raised portions, it should be noted that some, e.g., about 50%, depending on basis weight and bond frequency, compaction of the whole web generally occurs in the bonding step. However, an extensive compaction which results in appreciable fiber bonding in the areas between pattern bonds should be avoided. Raised portion heights of 0.015–0.030 are generally useful.

The hydrogen bonded areas of the product produced by the above described process generally have a thickness less than about 40% of the final web thickness, and usually less than about 20%. In other words, the final web thickness is generally at least 2.5 times the thickness of the bonded areas and usually at least 5 times. This high ratio of web thickness to bond thickness, in combination with the fact that there is substantially no fiber bonding other than in the pattern bonded areas, is believed to contribute significantly to the tactile properties and absorbency of the present webs.

As is well known, certain applications of paper products for which the present webs are useful generally require that wet-strength resins such as urea formaldehyde, melamine formaldehyde, polyamide, or polyamine be used. In general, these applications are facial sanitary wipes and towelling. In the preesnt process, the wet-strength additives can be added either prior to or after the bonding step, e.g., by spraying. Preferably, however, in order to minimize the effect of the additive on tactile properties and absorbency, an arrangement such as depicted in FIG. 8 is employed. Therein, a roller **48** rotates in a pan **50** containing a wet strength solution **52**. The roller **48** is partially submerged in the additive **52** and picks up resins which are metered to the patterned roll **46** via the rollers **54** and **56**. Using such an arrangement, wet strength resin is incorporated into the resultant web in the bonded areas only. As with the wet strength additive, it is also frequently desirable to apply starch or other adhesive to the web in order to prevent "linting." Once again, such can be applied in the present process by spraying the additive to the web either before or after bonding, such as at locations **42** or **58** in FIG. 1.

As regards the above-described process, the type of wood pulp employed is not particularly critical. Accordingly, pulps having relatively thin walled, long fibers (cedars) to coarse pulps with thick fiber walls (southern pine) can be used. The type of pulp employed will generally be determined by the type of texture desired; cedar pulps yielding a soft and fluffy texture, while southern pine pulps give a slightly wooly texture and more body. Long fibers are preferred for use herein since bond spacing in the web can be increased, thus making the product somewhat more flexible. Additionally, thin walled fibers have been found to somewhat enhance softness. In any event, it should be emphasized that the present invention concerns products which are substantially comprised of cellulosic fibers, particularly wood pulp, of short length. In comparison with ordinary textile fibers, the present fibers are of significantly shorter length, the length of textile fibers being on the order of at least ¾ inch while the fibers used herein generally have a length of less than ½ inch. More particularly, the fibers in the pulps described above have a length distribution of about 1–5 mm.

Sheets of pulp prepared by the Kraft process have been found to be most useful herein. However, so long as the fibers separated from the sheet can be subsequently bonded as described above, the manner of the preparation of the pulp is not particularly critical. Particularly when the present process is operated on a continuous basis, the selection of an appropriate pulp sheet will frequently be influenced by the ease with which picking can be accomplished. Accordingly, in such instances, low density sheets of unbeaten fibers are generally most desirable. To further facilitate picking, a debonding agent or a mechanical debonding operation can be employed. However, when using a debonding agent, it should only be used in an amount which does not excessively detract from the subsequent bonding which occurs at selected sites in the present process.

As has been indicated, webs prepared by the above-described process are particularly suitable for sanitary wipes and towelling, and, as such, have basis weights of 5–50 lbs. per 2880 sq. ft. and, preferably, 10–30 lbs. More particularly, at basis weights of 5–20 lbs., the present products are useful in bathroom and facial tissue applications, while at higher basis weights their principal use is as hand towelling. Quite surprisingly, the present webs can be used as single plies in many of those applications where, at similar basis weights, conventional products are composed of several plies in order to achieve the necessary softness and absorbency. Such is believed to be due to the unique structure of the present webs.

Referring again to FIG. 2, the novel product constructed in accordance with this invention is characterized by a continuum of randomly oriented fibers **60** interrupted by a pattern of bonded areas **62**. When a cross section is taken along a row of the bonded areas, as shown in FIG. 3, the bonded areas are seen to be alternately interrupted by fluffy mounds of substantially unbonded fibers. The fact that substantially no bonding is present in the mound areas is due to the absence of the strong surface tension forces which, as previously discussed, normally develop between fibers in water laid processes when the water is removed. Previously referred to FIG. 9 illustrates the substantially unbonded character of the fluffy mound areas. Being unbonded, the areas are quite soft.

Another characteristic of the webs prepared as described herein is illustrated by FIG. 10 which is a cross-sectional photomicrograph at 100× magnification of a portion of the web prepared as in Example I. As can be seen, fibers close to the surface of the fluffy mounds have a substantial orientation out of the basic plane of the web, (i.e., z direction orientation) as they leave the bonded area. This comparatively large Z direction orientation is believed to also contribute to the desirable tactile properties which the web possesses.

Aside from the fact that the presently illustrated webs contain substantial areas of unbonded fibers and contain fibers with high z direction orientation, the webs are also different from conventional products in that fiber orientation is more random in the basic plane of the web and the web less dense at equivalent basis weights. Both of these latter distinguishing features are also believed to be important in giving the product its desired combination of strength, absorbency, and improved tactile properties.

Fiber orientation in the basic plane of the web prepared as described above is quite random, and, consequently, the web exhibits substantially equal tensile strength in all directions. In particular, the tensile strengths in the machine and cross directions are quite close. The maximum ratio of tensile strength between these directions i.e., the orthotropic strength ratio (OSR), does not generally exceed 1.5 and usually is less than 1.2. As a result, the webs need only be bonded to the extent sufficient to develop strength for the particular end-use application; there being no resultant overbonding in one direction. Such, of course, results in improved tactile properties. Also, due to the randomness of the illustrated webs, highly desirable isotropic absorbency characteristics are present. The desirability of such characteristics are discussed in Bernardin, U.S. Pat. 3,455,778.

Webs prepared as discussed above also have a lower density at equivalent basis weights than conventional products. Such lower density is reflected in the measurement of both the real sheet density (RSD) and the apparent bulk density (ABD). The real sheet density is based on the volume enclosed by the opposite surfaces of the web. This is different from the apparent bulk density which is based on the volume between the two flat plates used to determine sheet caliper.

Two methods have been used for determining real sheet density. One method (method A) is based on an oil absorption measurement and involves saturating a previously weighed 2 15/16 inch x 2 15/16 inch sample of a single ply web with a low viscosity, pharmaceutical grade mineral oil (e.g., Whiterex 318). After saturation, the excess oil on the sample surfaces is removed by repeatedly laying the web on the surface of a sheet of polyethylene. Any surface oil wets the polyethylene and is transferred thereto upon lifting the saturated web. When no further oil transfer occurs, it is concluded that substantially all excess oil on the sample surfaces has been removed. This can be confirmed by observation with a stereo microscope. Such observation will show that the oil remaining in the sample is located in the fine internal capillary structure of the sample and not in the surface features such as crepe folds or bond depressions. After removal of surface oil, the sample is again weighed. By using the known specific gravities of the cellulose fibers and the oil in combination with the measured weight of the oil in the capillaries of the sample, the RSD can be calculated.

Method B involves embedding a sample with resin and microtoming it along the machine direction to form 80 sections, each 0.025 mm. thick. The sheet outlines in the projected images of these sections are then planimetered. The total area of the 80 sections times the section thickness gives the sample volume. The mass of the sample is calculated from the average basis weight of the precut web. The weight per unit volume (RSD) of the sample is quoted in gms./cc. Of the two methods described above, method A is less time consuming and is thought to be more accurate.

Characterizing a web in terms of apparent bulk density (ABD) is especially useful for uncreped sheets since the added volume due to crepe folds is not introduced. As used herein, ABD is measured by placing a 4 in.^{2} web sample in an Instron tester equipped with apparatus for the continuous recording of loads and sample deflection. The cross head is then lowered at 0.05 cm./mm. until a compressive stress of 0.25 grams/in.^{2} is indicated. This level is taken to indicate the uncompressed thickness of the sample. The sample is then removed from the tester and lowering of the cross head is continued with simultaneous recording of its motion until contact between the cross head and compression platen is obtained. The distance the cross head travels after initial contact with the sample is taken as the sample thickness. ABD is then calculated using this thickness, the known sample area, and the known sample basis weight.

The web densities discussed above, i.e., RSD and ABD, are directly influenced by the total bond area of the web, the spacing of the bonds, and the web's basis weight. Higher bond areas, closer bond spacings, or higher basis weights individually cause higher densities. On the other hand, lower densities can be achieved with low bond areas, large bond spacings, and low basis weights. Thus, at a given basis weight, the desired web density can be achieved by an appropriate selection of bond area and spacing.

Using the process described herein webs with basis weights of 5–50 lbs. can be prepared having RSDs of about 0.05–0.5 grams/cc. and ABDs of about 0.02–0.1 grams/cc. More particularly, webs with basis weights of 10–20 lbs., total bonded fiber areas of 8–20%, and bond area spacings at frequencies of 15–35 per inch across both web dimensions have RSDs of 0.10–0.23 and ABDs of 0.03–0.07. The variation of the density over the above ranges is in direct relationship to the variation of basis weight and total bond area and inversely related to bond

spacing. As hereinafter set forth in Table II, compared with conventional webs at equivalent basis weights, webs prepared as illustrated herein have lower real sheet densities. No comparison of the apparent bulk density is available since conventional products are creped. However, it is believed that if such a comparison were made prior to creping the conventional webs, the present webs would exhibit a lower ABD.

The following Examples I–VI illustrate the preparation of webs using the apparatus and method described with reference to FIG. 1. Table I gives the general process conditions for preparing these webs. The pulp fed to the picker **18** consisted of 70 lbs. sheets of Northern Soft Wood (mixture of Black Spruce, Jack Pine, and Balsam Fir) bleached Kraft pulp having a density of 0.6 grams/cc. The compacting rolls 32 were operated at a pressure of 12 lbs. per lineal inch and a smooth nylon roll **44** was used. The webs of the examples were dried by radiant heating after passing through the bonding nip. The embossing roll **46** was steel with diamond shaped embossing points arranged in a 60° triangle-type pattern. The foraminous wire **24** was operated at 27 ft. per minute for Examples I and II and at 13.5 ft. per minute for Examples III–VI.

TABLE I

Example	I	II	III	IV	V	VI
Basis weight, lbs./2,880 ft.^{2}	11	13	17	25.5	25.5	17
Moisture content prior to rolls 32 (percent)	8	8	8	8	8	8
Moisture content prior to bonding (percent)	20	20	24	30	30	24
Bonding pressure, lbs./lineal inch	149	188	149	149	149	149
Bonding pattern (points per inch)	19	25	19	19	19	19
Total bonded area, percent of web	10	10	10	10	10	10
Wet strength [1] (percent solids add on)					0.2	0.2
Starch [2] (percent solid add on)						0.3
Suggested single ply end use	(3)	(3)	(3)	(4)	(4)	(5)

[1] Sprayed on before bonding.
[2] Sprayed after bonding.
[3] Bathroom tissue.
[4] Towelling.
[5] Facial tissue.

The webs of several of the above examples were comparatively evaluated with conventional products for their strength and tactile properties. These evaluations were made as follows:

TENSILE STRENGTH

Tensile strength was measured with an Instron tester (Model No. TM–M) on web sample sizes of 0.5 inch x 3 inch). Measurements were made at a cross head speed of 0.067 inch per minute with the samples at 75° F. and a relative humidity of 50%. Tensile strength is reported as grams of load per inch of specimen width.

TACTILE PROPERTIES

The tactile properties are associated with the overall aesthetic effect one receives when handling a web. As such, it is not believed that any single objective test is completely representative of these properties. However, in an attempt to objectively illustrate tactile properties, the following three tests have been selected: the measurement of the compressive work value (CWV); the measurement of the crease recovery angle (CRA); and the measurement of the coefficient of friction (C_f).

The significance of the CWV as an indication of web softness is discussed in the aforementioned Sanford patent U.S. 3,301,746. As therein discussed, the CWV is the work required, in inch-grams, to compress a web to a loading of 100 grams per square inch with a contact area of four square inches. It is suggested that this work is similar to the work done by a person who pinches the surface of a sheet of paper between his thumb and forefinger to gain an impression of its softness; greater work being associated with increased softness. The present measurements of CWV were carried out in accordance with the procedure described by Sanford using an Instron tester (Model No. TM–M), samples four inches square, and a cross head speed of 0.05 cm. per minute. Prior to testing the samples were conditioned for 8 hours at 75° F. and 50% relative humidity.

CRAs were measured in accordance with the procedure described in ASTM test D1295 (ASTM Standards, part 24; 274–278) (1968 October). In this test, a sample of material is folded over and placed under a load of 500 g. for 5 minutes. Thereafter the load is removed and the material allowed to recover for 5 minutes, after which the angle of recovery (CRA) is measured. It is believed that this test reflects the limpness and compliancy of the web. Also, low recovery angle is believed to reflect the fact that the pressure points formed when a material is crumped will easily yield, and not give a harsh sensation.

A third test used to reflect softness involves the measurement of the C_f between the web surface and an essentially smooth sliding object. As with CWV measurement, the coefficient of friction measurement reflects the work done in compressing the web. However, since the measurement in this test is not carried out in a strictly normal compression direction, this test is felt to also reflect the work done in rubbing across the material such as one would do by sliding the material between the thumb and the forefinger. As with CWV, a higher coefficient of friction is thought to be associated with a softer material. The test is made by carefully laying a piece of the web on a smooth piece of plywood and clamping the web to the wood at one end. A sled (2.5 inches in the direction of motion and 1⅞ inches across, weighing 53.5 grams, and having as its sliding surface a stiff sheet of "Teflon" is placed on the web at the clamped end. The end is then raised slowly until the sled begins to move. The slope of the plywood is thereafter adjusted until the sled proceeds steadily down hill at a constant velocity of 1–2 inches per second. The slope of the plywood at this point is a direct measure of the coefficient of sliding friction (C_f) for "Teflon" on the test material.

Table II sets forth the results of the above discussed properties on the webs of Examples I and III and various conventional products. Orthotropic strength ratios and the above discussed densities are also presented.

which a web exerts at various levels of saturation. In turn, the suction pressure is an indication of the web's propensity to absorb more water at that particular level of saturation. For example, at equal saturation levels, the web exhibiting the higher suction pressure will more actively absorb additional water than the web with the lower suction pressure. These measurements are considered to be especially indicative of absorbency since, in actual use, a product rarely reaches the level of total saturation.

At saturation levels (grams H_2O/gram fiber) of 2, 4 and 6, the suction pressures (cm. of H_2O) of the Example III web were 40, 20 and 11, respectively. Such pressures indicate good web absorbency. In this respect, it has been noted that webs prepared according to the previously described process wherein a Kraft pulp is used, exhibit higher suction pressures at equivalent saturations and higher saturation capacities, than do conventional products, particularly those prepared with a sulfite pulp, which have aged for at least several months.

The above referred to absorbency characteristics of the webs prepared as described herein are believed to be due to the pore structure which exists in the fluffy mounds of the web. Since these mounds are of very low density and are comprised of substantially unbonded fibers, many fine pores are present. It is believed that the pore size distribution in the mounds is such that a large amount of the total pore volume of the web is comprised of pores which are particularly efficient in liquid absorption at intermediate levels of web saturation.

The remaining Examples, VII–X, also illustrate the invention. The webs of these examples were prepared on the apparatus shown in FIG. 4 as follows: Pulp, previously separated into its individual fibers, is placed in the container **64** having a screen **66** positioned on the bottom face. Air from a high pressure supply not shown is directed through the screen to cause fiber clumps to separate until they are small enough to pass through the screen. On passage through the screen the fibers **68** pass through the rounded metal funnel **70** and down through the cylindrical chamber **72** and the diverging chamber portion **74**. The fibers are collected on the fine screen **76** located at the bottom of the chamber **74**. Suction is provided by the fan **78**, and the screen **80**, located underneath the screen **76**, used to obtain uniform air-flow.

TABLE II

WEB	Basis weight, lbs./2,880 ft.²	RSD [1]	ABD	Tensile grams/inch M.D.	Tensile grams/inch C.D.	(OSR)	CWV	CRA M.D.	CRA C.D.	C_f
Example I	11	0.136	0.04	169	169	1	.59	----	----	----
Example III	17	0.144	0.06	226	222	1	.7	73	80	.272
Conventional creped 2 ply bathroom tissue	17.5	0.271	--------	266	132	1.95	.45	75	87	.233
Conventional creped 1 ply bathroom tissue	10	0.276	--------	228	107	2.1	.48	70	70	.233
Conventional creped 2 ply facial tissue	16.5	0.251	--------	286	168	1.7	.62	86	83	.223
Conventional creped 1 play facial tissue	18	0.499	--------	260	80	3.25	.38	101	78	.225

1 Measurement made only on a single ply of two ply products. Method (A) used for RSD.

As is evident from Table 2, the webs of Examples I and III have essentially equal tensile strength in the machine and cross directions and have low densities. Concerning the tactile properties, the present webs exhibit a definite trend in the direction of superior performance. This is particularly evident from the measurements of compressive work value and coefficient of friction. Furthermore, controlled subjective testing also illustrated that the webs of Examples I and III had superior tactile properties.

Absorbency of the Example III web was also evaluated using the Capillary Tension Cell Method. The procedure used was a modification of that described by Burgeni and Kapur (Textile Research Journal 37, No. 5 (356–366), (May 1967). For the present test, plain water was employed and equilibration times of 100 min. were used. This method can be used to measure the suction pressure

The tensile strengths of the webs in these examples were measured as previously described, and reported as grams/3 inch width. Different tests were used to illustrate the tactile properties. The tactile properties were subjectively determined. A harshness test is used to evaluate the roughness, coarseness, scratchiness, or raspiness of the sample surfaces. After the samples have equilibrated at the conditions of the testing room, one hand of the experimenter presses one side of the sample onto a flat surface while the sensitive areas of the fingers of the other hand are moved across the center of the sheet in the machine direction (M.D.) using a pressure normal to the use to which the product would be put. The sample is similarly stroked in the opposite direction and the harsher machine direction is compared with the other sample or samples. The experimenter alternately feels the samples being tested as many times as necessary to determine the relative harshness. The samples are then rated from 1 to 10, with the harshness increasing proportionately with the numerical rating.

A stiffness test is used to evaluate the resistance to crushing and is carried out by crushing one sample lightly in one hand and another sample in the other hand. While testing, the samples are held at arm's length and the pressures used in crushing are those normal to the use to which the product sample is to be put. The scale and rating are the same as for the harshness test, with the stiffness increasing with the numerical rating.

Overall softness is determined by grasping a sheet with both hands and subjectively comparing the qualities of one sheet to the qualities of another sheet. The tester observes particularly the flexure of the sheet and its smoothness upon stroking with the fingers.

EXAMPLE VII

Southern pine bleached-kraft pulp was dispersed in water and formed into sheets of 12 inch width and basis weights of about 300 lbs./2880 sq. ft. The sheets were formed on a conventional paper-making machine with a minimal amount of wet pressing to achieve a low sheet density. After being dried on a steam-heated drier drum, the sheet was cut into 1¾ inch strips and separated into its individual fibers by employing a picker roll.

About 2.1 grams of the defiberized pulp were placed into the container **64** shown in FIG. 4 and air formed into an 8" x 8" batt as previously described. This was compacted in a hydraulic press with 10 tons of force. The compacted batt was then conditioned for 2½ hours in a 97%-relative-humidity atmosphere, during which the web picked up about 20% moisture (on the moist-web basis).

The humidified web was then bonded by embossing in a two-roll calender stack having three-inch diameter rolls. The top roll had been knurled with a diamond pattern of 21 points per inch in the machine direction and 25 in the cross direction, each point having an area of 0.00026 sq. inches. The bottom roll was a smooth steel roll. The calender was operated with a loading of about 90 p.l.i. The sheet was permitted to wrap the pattern roll to make two passes through the pressure nip. Based upon the assumption that three rows of points were in nip contact, the bonding pressure per pass was 10,000 p.s.i.

A photomicrograph (20× amplification) of the bonded web is shown in FIG. 5.

The physical properties of the thus formed web were compared to a commercial two-ply towel material prepared by conventional water forming with the dried sheet being stripped from the drier drum with a doctor blade. The two-ply towel was made with polyvinyl alcohol being added to aid in the ply attachment. The results are shown in Table III:

TABLE III

Physical properties	Sample of— Air-formed 1-ply towel	Water-formed 2-ply towel
Basis weight, lbs./2,880 ft.²	28.7	27.4
Tensile strength grams/3 in., width:		
M. D	1,313	3,300
C. D	1,275	1,690
Percent stretch	5	32

The two towel samples were subjectively tested for tactile properties together with a sample of a commercially available water formed towel. The latter was formed by attaching two plies by peg-on-peg embossing. A polyvinyl alcohol solution was applied to the touching points of the opposite sheets in order to achieve ply adhesion. The two-ply sheet formed had depressions on both sides

of the sheet with substantial capillaries between the two plies. The results are shown in Table IV:

TABLE IV

Sample	Tactile properties Harshness	Stiffness
Air formed 1 ply towel	1	1
Water formed peg-on-peg embossed 2 ply towel	8	8
Water formed 2 ply towel	9	9

EXAMPLE VIII

A low density pulp sheet of Southern pine bleached-kraft pulp was formed, cut into strips and separated into its individual fibers, as in Example VII. About 1.1 grams of the fibers were placed in the container **64** (FIG. 4) and then air formed as in FIG. 4 to yield sheets having a basis weight of about 14 lbs./2880 sq. ft. The air formed sheets were then pattern bonded as in Example VII.

Two sheets of the air formed pattern bonded sheets were then ply bonded together with a hydraulic press. The stacked assembly consisted of a flat metal plate, a rubber cushioning gasket, a 5 mil. brass shim, a coarse 8 mesh wire, the two pattern bonded sheets or plies, and a second flat metal plate. The stacked assembly was placed in a hydraulic press and pressed with a force of 30 tons. FIG. 6 is a photomicrograph (12.6× amplification) of a portion of the two-ply bonded sheet.

The physical properties were compared to those of the water-formed two-ply towelling described in Example VII. The results are shown in Table V:

TABLE V

Physical properties	Sample of— Air-formed 2-ply towel	Water-formed 2-ply towel
Basis weight, lbs./2,880 ft.²	27.4	27.4
Tensile strength, gms./3 in, width:		
M. D	713	3,300
C. D	838	1,690
Percent stretch	6	32
RSD grams/cc. (Method B)	0.212	

The tactile properties of the two samples were compared with those of a peg-on-peg embossed two-ply towel made as described in Example VII. The results are shown in Table VI.

TABLE VI

Sample	Tactile properties Harshness	Stiffness
Air formed 2 ply towel	1	1
Water formed peg-on-peg embossed 2 ply towel	4.5	8.0
Water formed 2 ply towel	6.5	7.0

EXAMPLE IX

Cedar pulp with relatively long, thin fibers was dispersed in water and formed into 12" wide sheets of 300 lbs./2880 sq. ft. basis weight. These were cut into 1¾" strips and separated into the individual fibers as described in Example VII. About 1.4 grams of the fluffed pulp were placed in the container **64** and air formed into sheets having a basis weight of about 18 lbs./2880 sq. ft. The sheets were humidified for two hours at 97% relative humidity to reach a moisture content of about 20%.

The humidified sheets were bonded as in Example VII to form a sheet that was soft, smooth and flexible. To the touch, the sheets had a slight slippery or silky feel. FIG. 7 is a photomicrograph (20× amplification) of the sheet illustrating the three-dimensional texturing creating the resemblance of a finely woven fabric.

FIG. 3 is a photomicrograph (30× amplification) of a cross section of the bonded web which was taken through the center of the bonded areas. It demonstrates the fluffy mound configuration of the sheet. The bonded areas have an average thickness of 1.6 mils while the unbonded areas are relatively free of fiber bonding and have an average thickness of about 10.9 mils.

The physical properties of the sheet, suitable as a facial wipe, are compared to a commercially available facial tissue formed by conventional water forming. The conventional sheet had been folded over to form a two-ply product.

The results are shown in Table VII:

TABLE VII

Physical properties	Sample of— Air formed tissue	Water formed tissue
Basis weight, lbs./2,880 ft.²	18.5	18.8
Tensile strength, gm/3" width:		
M. D.	613	1,650
C. D.	613	400
Percent stretch	6	10-15
RSD grams/cc. (Method B)	0.205	

The tactile properties of the air formed sample are compared with those of a water formed sheet that is partially dried without compaction, then transferred to a knitted fabric and then pressed onto a drier to imprint the knuckle pattern of the fabric onto the sheet. The procedure is further described in Sanford et al. U.S. Pat. 3,301,746. The results are shown in Table VIII:

TABLE VIII

Tactile property	Sample of— Air formed tissue	Water formed tissue
Overall softness	1.0	2.8
Harshness	1	5
Stiffness	5	1

EXAMPLE X

A Southern-pine bleached-kraft pulp was air formed into a sheet having a basis weight of about 18 lbs./2880 ft.² in accordance with the procedure of Example VII.

The sheets were bonded as in Example VII with a diamond pattern having 21 x 25 spots per inch (0.00026 sq. in. per bond). A 5%-by-weight-solids solution of a wet-strength adhesive, was applied to the diamond pattern with a rubber roller. A nip pressure of 90 p.l.i. (corresponding to a pressure at the points of about 10,000 p.s.i.) was used, and the sheet was allowed to pass through the nip twice.

Two sheets were tested dry in an Istron tester and three samples were tested wet. The wet samples were placed in the Instron jaws dry, soaked with water applied from a squeeze bottle, and then allowed to condition for at least 45 to 60 seconds. The break loads of the wet and dry samples were tested with the following condition: 2 inch span, 3 inch width, a crosshead speed of 1 cm./min. and a chart speed of 50 cm./min. The dry break loads averaged 498 grams and the wet, 110 grams.

Thus, as illustrated by the above Examples VII–X the present invention provides novel, air-formed webs or sheets that include characteristics making them readily adaptable to wipe and towel applications.

I claim as my invention:

1. A soft, absorbent web having a basis weight of about 10–30 lbs. per 2880 ft.² comprising a continuum of random-laid wood papermaking fibers having a length of less than about 0.5 inch, the continuum being interrupted by a pattern of highly compacted self-bonded fiber areas occupying about 5–40% of the web area, the bonded areas being spaced less than about the average fiber length apart and the web fibers in the other areas forming substantially unbonded fluffy mounds having a thickness of at least about 2.5 times the thickness of the bonded areas.

2. The web of claim **1** wherein the bonded fiber areas are spaced across both dimensions of the web at a frequency of about 15–35 per inch.

3. A pattern bonded air laid web of papermaking wood-pulp fibers having a basis weight in the vicinity of 15 lbs./2800 ft.² and in which the bond pattern areas are hydrogen bonded, spaced less than an about average fiber length apart and occupy about 5–40% of the web area, and the areas outside the pattern areas remain soft and unbonded.

4. The web of claim **3** wherein the hydrogen bonds are spaced across both directions of the web at a frequency of about 15–35 per inch and the web has a thickness of at least about 5 times the thickness of the bonds.

5. A soft, absorbent web having a basis weight of 10–30 lbs./2880 ft.² comprising a continuum of dry formed cellulosic fibers having a length of less than about 0.5 inch, the continuum being bonded by a pattern of flattened self-bonded fiber areas which occupy about 5–40% of the web area and are spaced less than the average fiber length apart, the web thickness being at least about 5 times the thickness of the bonded areas and the real sheet density of the web being about 0.05–0.5 grams/cc., the variation of the density over said range being in direct relationship to the variation of the basis weight and total bond area and inversely related to the spacing between bonded fiber areas.

6. A soft, uncreped web having a basis weight of 5–50 lbs./2880 ft.² comprising a continuum of cellulosic fibers having a length of less than about 0.5 inch, the continuum being bonded by a pattern of bonded fiber areas which occupy about 5–40% of the web area, and are spaced less than the average fiber length apart, the web thickness being at least about 2.5 times the thickness of the bonded areas and the apparent bulk density of the web being about 0.02–0.1 grams/cc., the variation of the density over said range being in direct relationship to the variation of basis weight and total bond area and inversely related to the spacing between bonded fiber areas.

7. A soft, absorbent web with an orthotropic strength ratio of less than about 1.5 and having a basis weight of about 10–30 lbs./2880 ft.² comprising a continuum of air-laid wood pulp fibers, the continuum having its strength provided by a regular pattern of highly compacted and flattened self-bonded fiber areas occupying about 5–40% of the web area, the bonded areas being spaced less than about the average fiber length apart, and the web in the unbonded areas having a thickness of at least about 5 times the thickness of the bonded areas.

8. A soft absorbent uncreped web of papermaking wood fibers, air-laid to a basis weight in the vicinity of 15 pounds per 2880 square feet with strength suitable for single-ply uncreped facial or bathroom tissues, said web having a superimposed pattern of closely spaced indented zones spaced less than an average fiber length apart consisting of strongly self-bonded fiber, the flattened zones anchoring the unbonded areas as fluffy mounds of unbonded fibers.

9. A soft absorbent web of papermaking wood fibers comprising a continuum of dry-laid fibers having a basis weight of about 10–30 lbs./2880 ft.² containing a pattern of bonded fiber areas spaced less than an average fiber length apart from each other but occupying a minor proportion of the web area, each bonded fiber area being free of adhesive with its fibers densely compacted in the plane of the web to define strong interfiber bonds, and the fibers in the connecting web areas between the bonds defining fluffy unbonded mounds.

10. A soft absorbent web of papermaking wood fibers with length distribution of about one to five millimeters and with strength and softness in uncreped form suitable for single ply uncreped facial or bathroom tissues, comprising a continuum of dry-laid fibers having a basis weight of about 10–30 lbs./2880 ft.² containing a pattern of spotbonded fiber areas spaced less than an average fiber length apart from each other but occupying less than 40% of the web area, the fibers in the web areas between the bonds defining fluffy unbonded mounds and each bonded fiber area being free of adhesive with its fibers densely compacted to a paper thickness no more than 20% of the heights of the mounds.

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