United States Patent [19]

Curtis et al.

[11] **3,915,202**

[45] **Oct. 28, 1975**

[54] **FOURDRINIER PAPERMAKING BELTS**

[75] Inventors: **Donald R. Curtis; Christian B. Widen,** both of Appleton, Wis.

[73] Assignee: **Albany International Corporation,** Glens Falls, N.Y.

[22] Filed: **May 3, 1974**

[21] Appl. No.: **466,663**

[52] **U.S. Cl.** .... **139/425 A;** 162/DIG. 1; 162/348

[51] **Int. Cl.^{2}** **D03D 15/00;** B01D 39/16

[58] **Field of Search** .... 139/425 A, 425 R, 383 A, 139/420 R; 162/DIG. 1, 358, 348; 245/8, 10; 74/231 P; 198/193

[56] **References Cited**

UNITED STATES PATENTS

2,903,021	9/1959	Holden et al.	139/425 A
2,992,681	7/1961	Hornbostel et al.	162/DIG. 1
3,207,659	9/1965	Wagner	139/425 A
3,421,230	1/1969	Ward	139/425 A
3,473,576	10/1969	Amneus	139/425 A
3,573,164	3/1971	Friedberg et al.	139/425 A
3,851,681	12/1974	Egan	139/425 A
3,858,623	1/1975	Lefkowitz	139/425 A

FOREIGN PATENTS OR APPLICATIONS

37-17756	10/1962	Japan	139/425 A
45-16242	6/1970	Japan	162/DIG. 1

Primary Examiner—James Kee Chi

[57] **ABSTRACT**

A woven Fourdrinier Papermaking Belt made of synthetic polyester cross-machine direction strands and machine direction strands, in which the cross-machine direction strands have a low modulus of elasticity measured in their woven heat-set condition and the machine direction strands have a higher modulus of elasticity, both modulus measurements being made at an extension of the strand at which the crimp has just been substantially pulled out.

7 Claims, 17 Drawing Figures

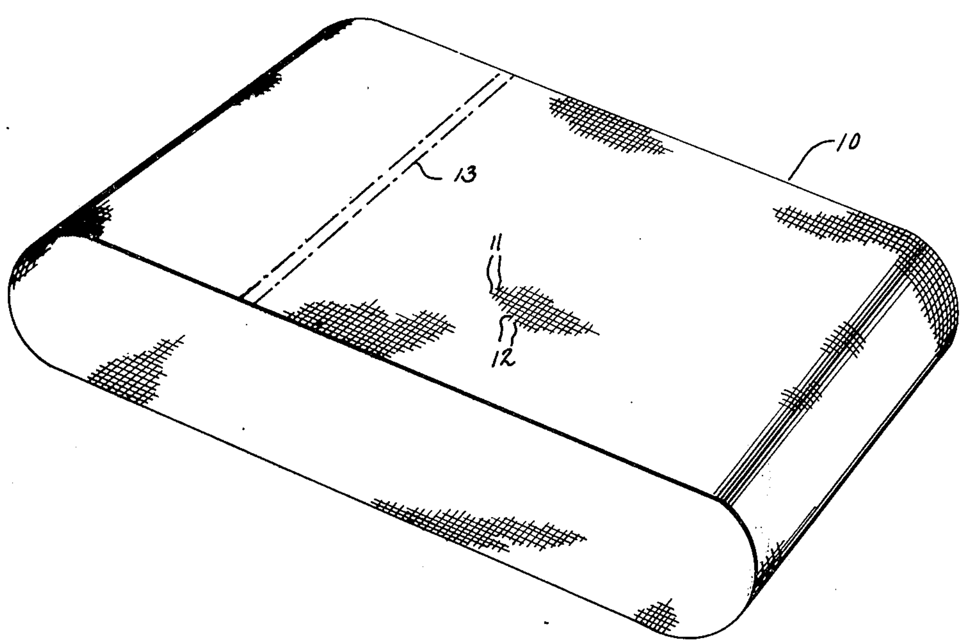


Fig. 1

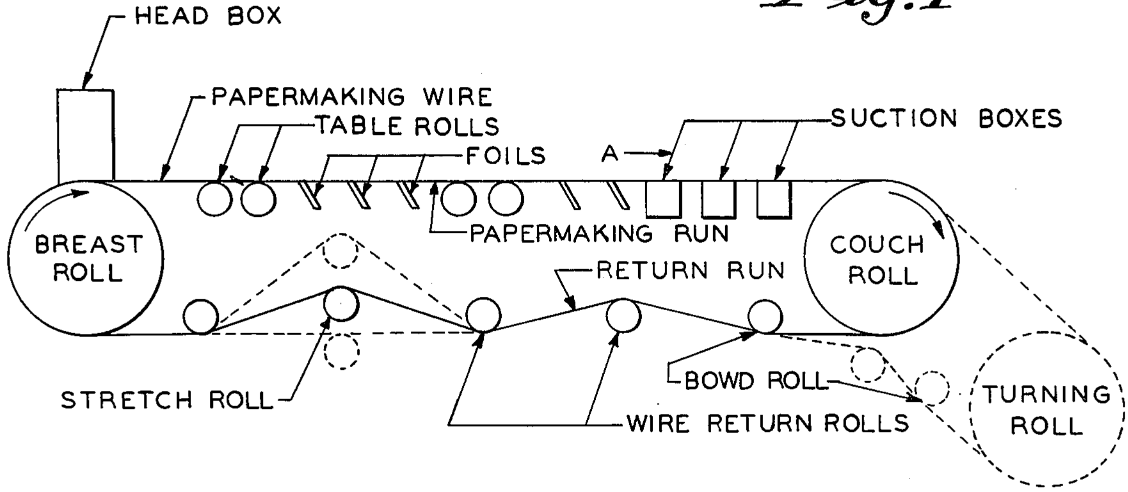


Fig. 2

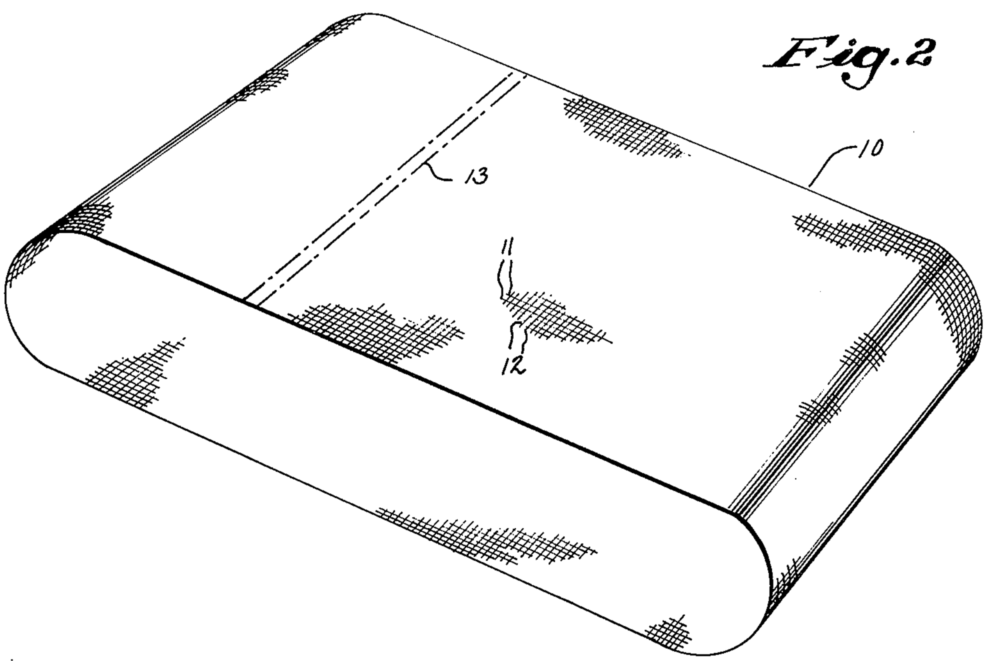


Fig. 3
PRIOR ART

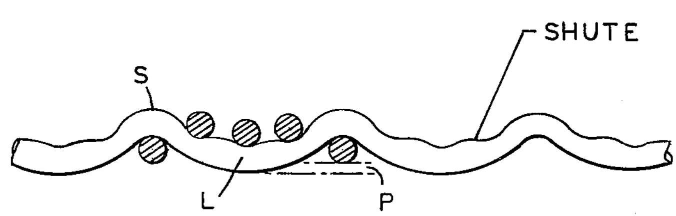


Fig. 4
PRIOR ART

Fig. 5
PRIOR ART

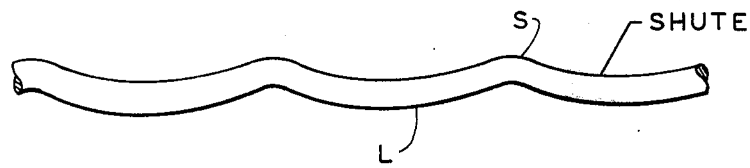


Fig. 6
PRIOR ART

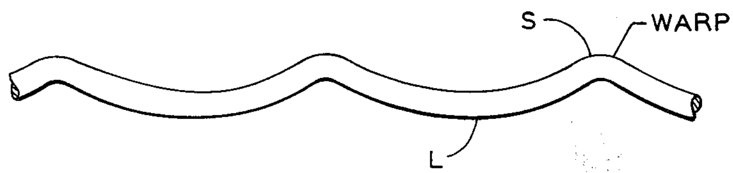


Fig. 7
PRIOR ART

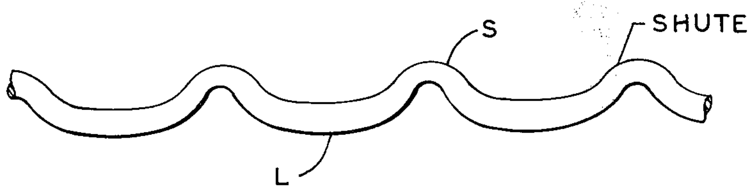


Fig. 8
PRIOR ART

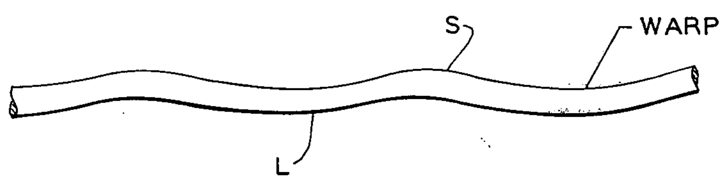


Fig. 9

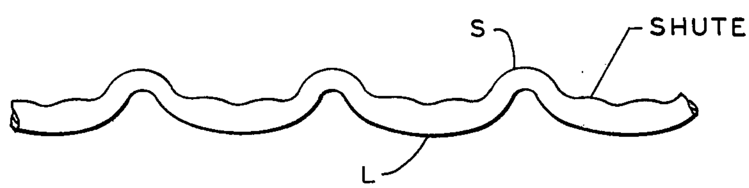


Fig. 10

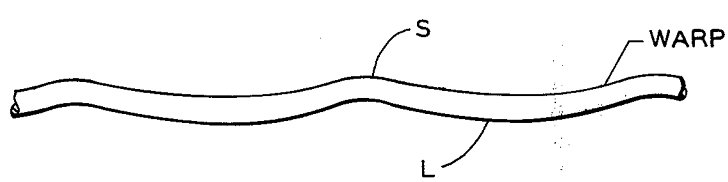


Fig. 11

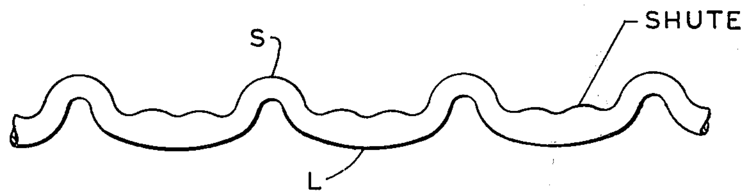
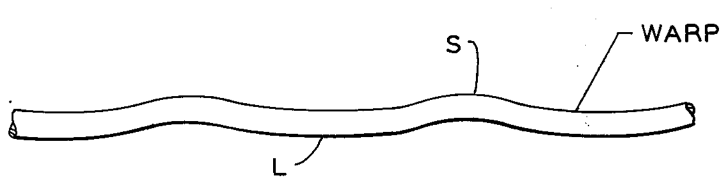


Fig. 12



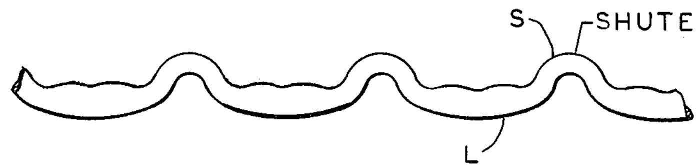


Fig. 13

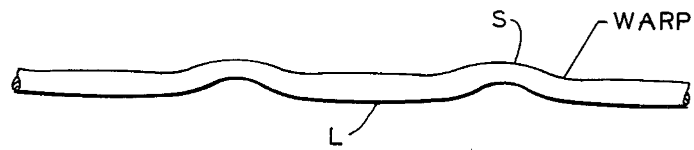


Fig. 14

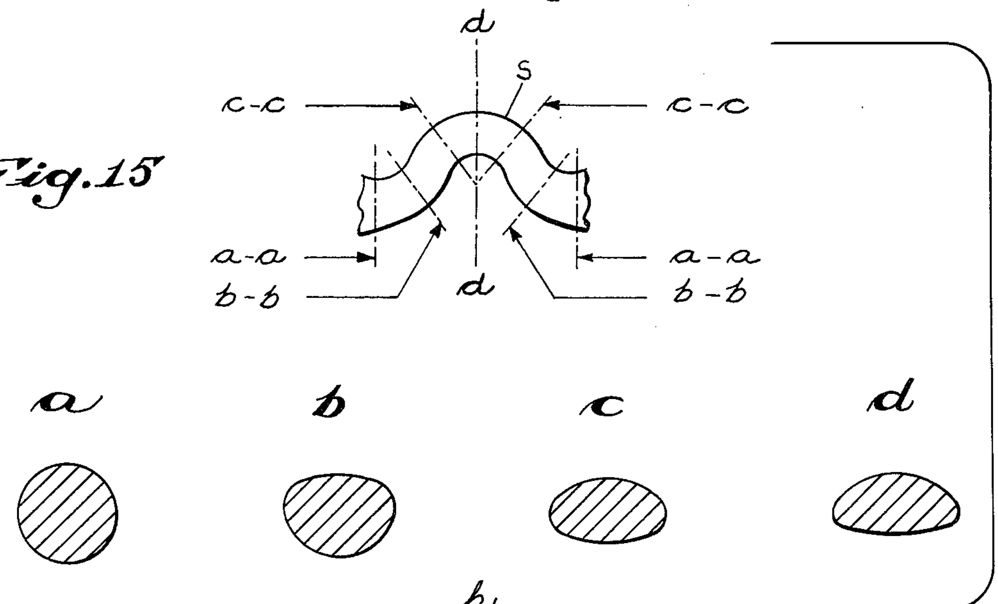


Fig. 15

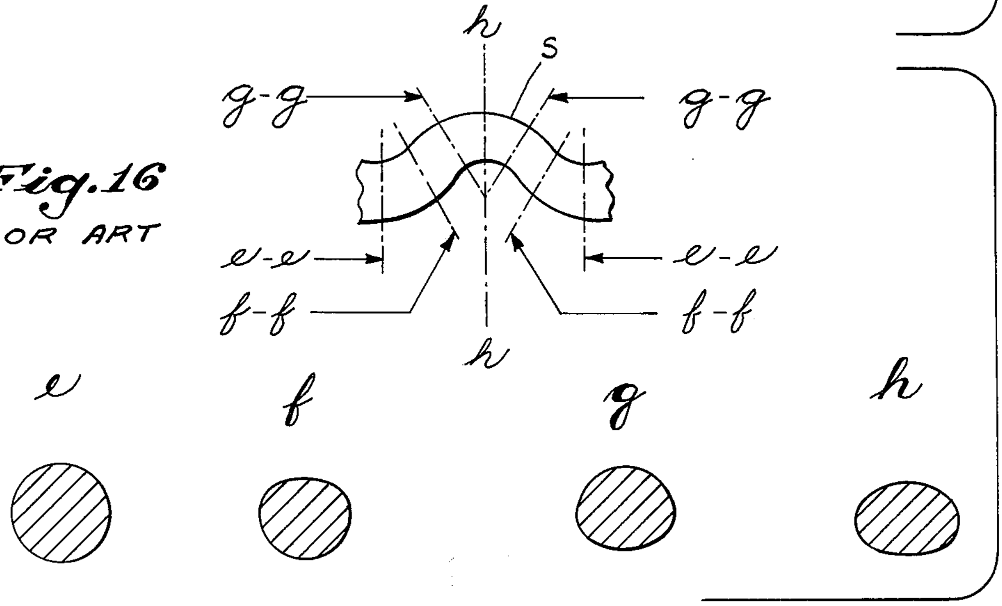


Fig. 16
PRIOR ART

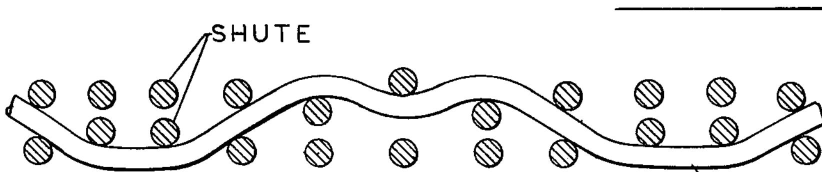


Fig. 17

FOURDRINIER PAPERMAKING BELTS

BACKGROUND OF THE INVENTION

1. Field

This invention relates to the field of papermaking belts for a Fourdrinier papermaking machine, more specifically to a papermaking wire made of plastic members.

2. Description of the Prior Art

In a Fourdrinier papermaking machine, the furnish or slurry of wood fibers is fed onto a traveling endless belt or wire which is supported and driven by rolls associated with the machine. The papermaking belt may be formed from a length of woven fabric having its ends seamed together to form an endless belt, or it may be woven on a loom as an endless belt.

FIG. 1 depicts the forming section of a typical Fourdrinier machine. The papermaking belt is trained about the breast roll at one end and the couch roll at the other end, the couch roll being driven to rotate the belt. The upper run of the papermaking belt is the paper forming surface (referred to below as the papermaking run) and travels across table rolls, foils and suction boxes. The furnish is fed onto the papermaking belt from the head box and is formed into a continuous web as water is drained from it while it travels along the belt until it is removed at the couch roll and transferred to the press section of the machine for pressing and subsequent processing. The return run of the papermaking belt leaves the couch roll and passes across wire return rolls and an adjustable stretch roll positioned between the breast and couch rolls.

The increased use of large papermaking machines has resulted in the Fourdrinier being as large as 100 to 120 feet long (making the papermaking belt having a circumferential length of 200 to 240 feet) and up to 400 inches wide, and the belt travels at high speeds as fast as 5,000 feet per minute in the modern machines.

In order to function properly and have a suitable useful life on the machine, the papermaking belt must be dimensionally stable in both the machine direction and the cross machine direction ("Machine direction" refers to the direction of travel of the belt from the breast roll to the couch roll, arrow A in FIG. 1, and the "cross-machine direction" is perpendicular thereto.) Dimensional instability in the machine direction will cause the papermaking belt to extend or stretch while dimensional instability in the cross-machine direction will result in width contraction of the belt.

The stretch characteristic of a papermaking belt is of importance during both the installation of the belt on a machine and during the actual operation of the machine. Installation is generally accomplished by swinging down the breast roll of a machine or partially dismantling the machine, fitting the belt into position and then stretching it to fit the machine under a specified tension. Papermaking machines have the capacity to absorb a certain amount of belt stretch within a designed range; a survey of 85 machines showed 40 percent had a stretch capacity of less than ½ percent, 28 percent had a stretch capacity of ½ to ¾ percent, 22 percent had a stretch capacity of ¾ to 1 percent, and the balance had a stretch capacity of over 1 percent. If the papermaking belt has an extension greater than the stretch capacity of the machine it is to be installed on, the belt must be made shorter than the minimum length of the machine and the fabric stretched when it is installed. However, it is important that extension of the belt be kept as low as possible in order that the belt not unduly elongate during operation. The belt is under tension during operation of the machine, with the tension on the papermaking run being greater than the tension on the return run. Typically, low load machines will have a tension of 30 – 40 pounds per linear inch (PLI) on the papermaking run and 15 – 20 PLI on the return run, medium load machines will have a 50–60 PLI tension on the papermaking run and about 25 PLI on the return run, and high load machines will have 70–80 PLI tension on the papermaking run and about 35 PLI on the return run.

The tensions developed during operation of the papermaking machine will tend to extend or stretch the papermaking belt. If the belt extension is within the stretch capacity of the machine, the stretch roll can adjust to maintain proper tension on the belt. However, if the belt extends more than the stretch capacity of the machine, continued extension of the belt will result in a decrease in the tension that will cause slippage of the belt so that it cannot be driven at the designed speed. A small amount of slippage can cause poor paper transfer and paper breaks when the web leaves the belt to go into the press section of the machine, and can cause physical damage to the papermaking belt. If the slippage is intermittant, there will be differences in the weight of the paper web being made on the belt; the flow of the furnish from the headbox onto the belt is at a constant speed so that variations in speed of the belt will result in irregularities in the weight of the paper being made on the belt due to variation in the amount of pulp on the wire at any given time. A large amount of slippage can cause the belt to stall completely or stop on the machine, thereby causing the pulp in the head box to overflow the belt and spill onto the floor. While a large degree of slippage will obviously require an immediate change of the belt, even moderate slippage which adversely affects the papermaking function of the belt will require its removal and change, and a low degree of slippage insufficient to affect the papermaking operation will accelerate wearing of the papermaking belt.

Dimensional instability of the papermaking belt in the cross-machine direction manifests itself as width contraction during operation of the machine. Width contraction is associated with crimp interchange which takes place between the machine direction strands of the papermaking belt that are under tension and the cross-machine direction strands in the belt. As the papermaking belt extends or stretches under tension, there is a corresponding increment of narrowing or width contraction of the belt. This may not normally be a problem with a narrow papermaking machine, but becomes a significant problem with machines of increased width. The width contraction of a belt can be on the order of 0.3 percent, so that a 300 inch wide belt, for example, would exhibit a contraction of almost 1 inch. As the papermaking belt experiences a change in width from a narrow width on the papermaking run (high tension) to a wider width on the return run (low tension), a ridge will develop in the belt on the return run unless a spreader apparatus such as a Bowd roll is installed on the machine or unless the papermaking belt itself has a minimal degree of width contraction. The ridge will typically form in the center ⅓ of the belt and usually develops because the belt cannot recover to the proper width prior to the time it goes over the first return roll on the machine; since the excess material resulting from the width change has to go someplace, it will normally develop into a raised portion or ridge. Just a few minutes running of a belt having a ridge will cause marking of the paper being made on the papermaking run and will ultimately lead to failure of the belt in the ridge area. Even though the Bowd roll corrects this problem, it is a source of maintenance problems and requires frequent replacement of its rubber cover. In addition, it is either difficult or impossible to place a Bowd roll in the desired position on many paper machines. Many papermakers do not like to use a Bowd roll because of its maintenance problems and because of having additional equipment that must be considered when changing the papermaking belt.

The last ten years or so has seen increasing use of plastic materials for the construction of papermaking belts, typically plastic monofilaments which are woven in the desired pattern. Plastic belts exhibit a number of highly desirable properties which have led to their increased acceptance, and it has been estimated that in five years or so about 85 percent of the papermaking machines will utilize plastic papermaking belts. However, the plastic belts do not have the dimensional stability of the metal papermaking belts that were typically used before plastic belts; thus, at a given tension, the stretch or extension of a plastic papermaking belt, for example, is greater than that of a metal belt. This characteristic has led to several processing steps that are employed to improve the dimensional stability of the plastic belt.

Typical manufacture of a plastic papermaking belt involves first weaving the fabric either as an endless belt or as a flat fabric and then subjecting it to a subsequent heat setting operation. The heat setting operation allows the cross-direction strands to contract, thereby straightening out the machine direction strands while increasing the crimp in the cross-direction strands. This minimizes the crimp interchange as the belt is running on the machine, and thereby minimizes or reduces the width contraction of the belt. It is possible to carry such subsequent heat setting to a stage in which the machine direction strands are almost straight. The extension or stretch characteristic of the fabric is also reduced by the reduction of the crimp in the machine direction due to such heat setting. In general, the straighter are the machine direction strands, assuming the same number and diameter of strands, the lower the extension of the fabric will be. This type of heat setting is often referred to as off-loom heat setting since it is carried out after the fabric has been woven on a loom, removed therefrom and arranged in a special heat setting apparatus such as a tenter frame.

Off-loom heat setting has a disadvantage in that the fabric is narrowed substantially during heat setting; this narrowing can be as much as 20 percent reduction in the width of the fabric. When measured from the width of the fabric as actually woven on the loom, the width reduction can be as great as 25 percent. This means that wider looms are required to weave fabrics wide enough for the large belts now being employed on many papermaking machines. For example, a belt that was to be 300 inches wide in the finished condition would have to be made of fabric woven about 400 inches wide if it underwent the off-loom heat setting treatment.

Because off-loom heat setting imposes requirements for wider looms and extra apparatus for carrying out the heat setting operation, on-loom heat setting has been developed to improve the stability of the woven cloth according to which a heat source is added to the loom and operated during the weaving operation so as to heat set the crimp into the fabric as it is being weaved. However, on-loom heat setting requires high weaving tensions to physically force crimp interchange between machine direction and cross direction strands while on the loom. On-loom heat setting results in a fabric with an extension under running loads which is 20 to 30 percent greater than that of off-loom heat setting, and the width contraction characteristic of the fabric (even though utilizing high loom tensions) does not approach that of off-loom heat set fabric; it is usual that on-loom heat set fabric will have a width contraction about three times that of an off-loom heat set fabric. Thus, for example, a 78 mesh cloth with on-loom heat setting typically will have a width contraction of 0.3 percent, but the same cloth structure when treated by off-loom heat setting would have a width contraction of about 0.1 percent, and it is not difficult to obtain 0.05 percent contraction, measured at **30 PLI**. On-loom heat setting also has disadvantages in that the physical limit of the loom has been reached in some cases, manufacturing problems arise by reason of working at the upper limit of the equipment, and there are restrictions on the number of cross-direction strands per inch that can be woven into the fabric, so that latitude during weaving would be possible if the tensions could be varied and one could still obtain good physical properties to the finished cloth.

SUMMARY OF THE INVENTION

The present invention provides a Fourdrinier papermaking belt made of synthetic material which resolves the problems discussed above through the provision of a fabric wherein the cross-machine strands have a crimp architecture which differs substantially from that heretofore employed with synthetic plastic materials as utilized in papermaking belts. The crimps or knuckles in the cross-machine strands of a papermaking belt of this invention, after heat setting, more closely conform to the machine direction strands in the belt than is the case with conventional synthetic plastic papermaking belts, and the cross-machine strands employed in the papermaking belts of this invention undergo a greater distortion of cross-sectional shape than is found with the conventional materials.

It has been found that, according to this invention, a superior fabric for papermaking belts can be achieved more efficiently and without loss of dimension, after weaving and heat setting, by employing for the cross-machine strands plastic materials distinctly different from those conventionally used in the manufacture of papermaking fabrics. Conventional cross-machine strands are typically made of plastic material that has moderately high values of either crystallinity or orientation, or both, before weaving which closely approach their ultimate values of crystallinity or orientation after weaving and heat setting; in contrast, it has now been found that the use of plastic material for the cross-machine strand which in its state prior to weaving has a low degree of crystallinity or orientation and exhibits a proportionately greater percentage increase in crystallinity or orientation upon weaving and heat setting leads to a superior fabric and a greater level of conformability with the machine-direction strands. Thus, whereas a typical prior art synthetic plastic polyester material when used in monofilament form prior to weaving and heat setting had a crystallinity of approximately 80 percent of the crystallinity attained after weaving and heat setting, the materials employed in the papermaking belts of this invention would have a polyester monofilament which had a crystallinity before weaving and heat setting of less than about 40 percent of its ultimate crystallinity.

Still more specifically, this invention provides for the construction of Fourdrinier papermaking belts of synthetic polyester materials having a modulus of elasticity in the woven heat-set condition that is substantially less than the modulus of commonly used polyester materials, most effectively on the order of or less than 0.95×10^4 psi per 10 percent extension, measured as herein defined. In general, polyester materials having the lower modulus in accordance with this invention also exhibit a higher degree of elongation prior to weaving and heat setting than conventional polyester materials employed for Fourdrinier papermaking belts.

DESCRIPTION OF THE DRAWINGS

This invention is more fully described with reference to the accompanying drawings, wherein:

FIG. **1** illustrates the forming section of a typical Fourdrinier papermaking machine;

FIG. **2** is a perspective view of a Fourdrinier papermaking belt;

FIG. **3** illustrates the configuration of a cross-machine strand in a prior art belt, and FIG. **4** illustrates a machine direction strand of the same belt;

FIG. **5** illustrates the configuration of a cross-machine strand in a prior art belt before heat setting, and FIG. **6** illustrates a machine direction strand of the same belt before heat setting;

FIG. **7** illustrates the cross-machine strand of FIG. **5** after heat setting; and FIG. **8** shows the strand of FIG. **6** after heat setting;

FIG. **9** illustrates a cross-machine strand of the fabric of Example **1**; and FIG. **10** illustrates a machine direction strand thereof;

FIG. **11** illustrates a cross-machine strand of the fabric of Example **2**; and FIG. **12** illustrates a machine direction strand thereof;

FIG. **13** illustrates a cross-machine strand of the fabric of Example **3**; and FIG. **14** illustrates a machine direction strand thereof;

FIG. **15** is an enlarged view of a short knuckle of the fabric of FIG. **9**, together with cross-sectional views thereof; and

FIG. **16** is an enlarged view of a short knuckle of the fabric of FIG. **3**, together with cross-sectional views thereof; and

FIG. **17** is a machine direction sectional view of a double layer Fourdrinier belt made according to this invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

1. Description of Tests

This description and the claims refers to the terms "modulus of elasticity" and "elongation" and the following describes the manner in which each of these two characteristics is measured.

Modulus of elasticity, sometimes also herein referred to merely as modulus, is determined by examination of the tensile load-extension curve of the various materials. This characteristic is employed to compare various materials after they have been woven and heat set so as to be in a crimped condition. Because the crimps have different geometrical configurations, direct comparison during the initial stage of extension is not possible due to the bending which occurs. Therefore, it is only after the crimp has been substantially pulled out of the various samples and they are being extended as linear elements, that a direct comparison of the material properties is legitimate. Modulus as herein set forth was measured by employing a 2 inch nominal (or crimped) gage length sample in an Instron tensile tester, using a jaw speed of 2 inches per minute, and then drawing a tangent to the load-extension curve at the extension at which the crimp has just been substantially removed. This extension value was determined by direct visual observation of the specimen with a magnifying glass as the specimen was undergoing extension. Calculation of the modulus at this extension must be corrected for the fact that at the point of removal of the crimp, the actual gage length or the linear length of the sample between the jaws of the tester is slightly different for the various samples because of differences in crimp contraction. Data are reported as the average of 5 specimens of each material in terms of psi per 10 percent extension (psi/10 percent extension).

Elongation at break ("elongation") of an unwoven and non-heat set strand is determined by placing a specimen of each material in a Scott Model X-3 tensile tester wherein the material specimen is clamped in Calloway jaws. The sample specimens were 5 inches long between jaws; and the jaws were pulled apart at the rate of 20 inches per minute. The elongation of each sample was measured at break, and data are reported as the average of 3 specimens for each material.

Extension under load of a woven fabric is determined by placing a fabric specimen with a 10 inch gage length and 1 inch width in an Instron tensile tester and pulling the jaws apart at a crosshead speed of 20 inches per minute while subjecting the specimen to a load ranging from 1 to 50 pounds; data reported are the average of 3 specimens of each fabric.

Width contraction refers to the narrowing of a papermaking belt when subject to tensile loading. Width contraction data reported herein represent the percentage contraction of a belt at a tension of 30 PLI. It is measured by installing a finished papermaking belt between rollers on a stretching table that incorporates load cells. The initial width is measured with the belt under zero tension. The width of the belt is measured when a tension of 30 PLI is applied to the belt, and width contraction is the percentage decrease in width at 30 PLI in comparison to the initial width of the belt. For example, a belt with an initial width (under zero tension) of 300 inches that contracts to 299 inches at 30 PLI tension has a width contraction of 0.333 percent. The belt is rotated when under load to allow the area to be measured to contract, and the width is measured with the belt stopped but with the load still applied to the belt. Width measurements for both zero tension and 30 PLI are made at the same position on the belt.

2. General Description

FIG. **2** illustrates an endless belt **10** utilized as the papermaking belt for a Fourdrinier machine. The belt **10** is formed of individual machine-direction strands **11** and cross-direction strands **12** which are woven together in various patterns to provide the finished fabric. The papermaking belt **10** may be formed from a flat length of fabric woven on a suitable loom and its ends seamed together as shown by the dotted lines **13** to form an endless belt, or the belt may be woven in an endless condition on appropriate looms. When the belt is made from a flat fabric that is to be seamed, individual warps are strung longitudinally on the loom through a set of heddles and are raised and lowered by movement of the heddles in accordance with the preselected weave pattern to form what are known as triangular sheds. Shute material is carried in a shuttle and is caused to move transversely of the loom and pass through the sheds formed by raising and lowering the warps, after which a lay is actuated to beat the wefts in the apex of the sheds or the beatline. When woven flat in this fashion, the warps become the machine-direction strands of the finished papermaking belt, and the shutes become the cross-machine direction strands of the finished belt. If the belt **10** is woven as an endless belt, the shutes are supplied from one or more shuttles and woven in the form of a continuous helix about warp wires which extend lengthwise of the loom, but the endless woven material is cut parallel to the shutes so that the shutes form the machine-direction strands and the warps the cross-direction strands in the finished belt.

The warp and shute strands are woven together in various repeating patterns to form the finished belt, the "plain weave" being one in which each shute passes successively over one warp and under the next, the "twill" (or sometimes called semi-twill) weave in which each shute passes over two warps and under the next warp, a "four-shed" weave in which each shute passes alternately over one warp and then under the next three warps, or a so-called "full-twill" weave in which each shute passes alternately over two warp strands and then under two warp strands.

During the weaving process, the shute and warp strands become crimped or curved to form knuckles. The shutes (cross-machine direction strands) in a flat-woven fabric heat set on the loom are generally more highly crimped than the warps (machine direction strands) which are slightly crimped to a sufficient degree to allow seaming of the fabric. In endlessly woven fabric and in flat-woven fabric seamed and heat set off the loom, the cross-machine direction strands will assume a greater degree of crimp than the machine direction strands which can be straight or almost straight.

3. Prior Art Papermaking Belts

FIGS. **3** and **4** illustrate shute and warp configurations for a typical prior art papermaking belt as manufactured by the assignee of the present application, wherein the fabric is woven flat on a loom and seamed to form an endless belt. The fabric illustrated in FIGS. **3** and **4** is of the so called "four-shed" weave wherein each shute passes alternately over one warp strand and under the following three warp strands. The illustrated sections are of a fabric woven from polyester monofilament warp material having a 0.20 mm diameter and polyester shute material having a diameter of 0.25 mm, in which the fabric was woven in a 78 × 57 mesh, by which is meant it had 78 warps per linear inch and 57 shutes per linear inch. The warp material was strung

longitudinally on the loom under a tension of 350 grams per strand, and the fabric was heat set on the loom using a temperature of 390°F.

The shute as illustrated in FIG. **3** is crimped to have alternating short and long knuckles. Considering first the short knuckles S, it will be noted that the geometry of a knuckle S is such that it has sloping arms interconnected by a bight portion of a relatively large radius of curvature. A long knuckle L has a larger radius of curvature than knuckle S. A measure of the degree of crimp in the shute is what is herein referred to as the plane difference defined as the difference in height between the bottom surface of a long knuckle of the shute and the bottom surface of an adjacent warp, which is indicated as P in FIG. **3.** For the specific material illustrated herein, this plane difference was 0.0031 inches wherein the shute knuckle extended below the adjacent warp. When placed on a papermaking machine, the long shute knuckle surface of the fabric would be the wear surface of the papermaking belt.

The woven fabric of FIGS. **3** and **4** showed an extension under a load of 50 PLI averaging about 1.36 percent. This cloth was woven from shute material of polyester synthetic as typically used, and the shute in its crimped and heat set condition has a modulus of elasticity of 1.78×10^4 psi per 10 percent extension. The monofilament material used therein, prior to weaving, had an elongation of about 48 percent at break.

FIGS. **5–8** are sectional views of another conventional papermaking belt, this time made from fabric which has been heat-set off the loom after the weaving process was completed. The fabric of FIGS. **5–8** was made with the same warp and shute materials utilized with the fabric of FIGS. **3** and **4,** and in the same weave. As woven on the loom the fabric had a mesh count of 65 × 57. FIGS. **5** and **6** illustrate the shute and warp configurations, respectively, following weaving but prior to heat setting. It will be noted from comparison of these two figures that, at this stage of its manufacture, the shute or cross-direction strand has less crimp than the warp or machine direction strand. Following the weaving, the fabric was arranged in a tenter frame apparatus and subjected to a thermosetting treatment at 400°–450°F under tension, during which the crimp interchange caused the mesh count to change to a 75 × 55 fabric, indicating that the fabric narrowed up approximately 15 percent during the thermosetting operation. This caused a marked change in the geometry of the shute and warp strands which are illustrated, respectively, in FIGS. **7** and **8.** Comparison of FIG. **7** with FIG. **5** shows that the shute or cross-direction strand has now assumed a greater degree of crimp, whereas comparison of FIG. **8** with FIG. **6** reveals that the warp or machine-direction strand has straightened out. These drawings illustrate the substantial crimp interchange which takes place between the shute and warp strands during the thermosetting operation. Comparison of the shute configuration in FIG. **7** with the shute in FIG. **3** indicates that the short knuckles S of the fabric as shown in FIG. **7** have more vertical arms and therefore a shorter radius of curvature in comparison to the short knuckles of the shute of the fabric of FIG. **3.** The fabric of FIGS. **5–8** had an extension at 50 PLI of 1.1 percent. The shute in its woven and heat set condition had a modulus of elasticity of about 1.18×10^4 psi/10 percent extension and prior to weaving had an elongation of about 48 percent at break.

4. Fabric of Present Invention

The present invention provides Fourdrinier papermaking belts utilizing fabric wherein cross-direction strands or shutes having different knuckle configurations than the shute strands illustrated in FIGS. **3–8** are obtained through the use of shute materials having a different deformation characteristic than the shute material of the fabrics of FIGS. **3–8.** More particularly, polyester materials employed as the shutes or cross - machine strands in Fourdrinier belts of this invention have a significantly higher elongation at break in their unwoven state than in the typical prior art shute material. Further, the polyester cross-direction strands in the belts of this invention have a much lower modulus of elasticity measured in their woven and heat set state upon removal of crimp than the modulus of the shutes of the preceding prior art fabrics.

In the following examples various polyester materials are used as the cross machine direction strands to weave Fourdrinier cloth in the same pattern and with the same warp material as the fabrics illustrated in FIG. **3–8.** Shute strands in the following examples have a diameter of 0.25 mm and the warp strands have a diameter of 0.20 mm. The fabrics were woven flat and heat set while on the loom at a temperature of 390°F. Examples 1–5 illustrate the desired reduced extension under load of the finished fabric, and Examples 6–8 illustrate the desired reduction in the width contraction obtained through utilization of the present constructions in comparison to the prior art construction of Example 9.

EXAMPLE 1

Polyester monofilament having an elongation of about 111 percent was woven as the shute into Fourdrinier fabric wherein the warp strands were strung on the loom under a tension of 175 grams per strand. The woven fabric had a mesh of 79 × 51, i.e. 79 warp strands per linear inch and 51 shute strands per linear inch. The woven fabric had an extension of 1.02 percent. The plane difference, P, was 0.0044 inches. The shute in the woven fabric had the configuration illustrated in FIG. **9** and the warp strand had the configuration illustrated in FIG. **10.**

EXAMPLE 2

Polyester monofilament having an elongation of about 105 percent was woven as the shute into a 79 × 55 mesh Fourdrinier fabric wherein the warp strands were strung on the loom under a tension of 300–310 grams per strand. The finished fabric had extension of 1.02 percent. The plane difference, P, was 0.0044 inches. The shute strands in the woven condition had a configuration as shown in FIG. **11** and the warp strands a configuration as shown in FIG. **12.**

EXAMPLE 3

Polyester monofilaments having an elongation of about 96 percent were woven as the shute into Fourdrinier fabric having a 79 × 55 mesh. The warp strands were strung on the loom at a tension of 340–350 grams per strand. The finished fabric had an extension of 1.11 percent, and the plane difference, P. was 0.0038 inches. In the finished fabric, the shute strands had the configuration of FIG. **13,** and the warp strands the configuration of FIG. **14.**

EXAMPLE 4

Fourdrinier cloth in a 79 × 55 mesh was woven from polyester monofilament having an elongation before weaving of about 125 percent as the shute and with the warp under a tension of 200–210 grams per strand. The fabric had an extension of 1.2 percent and a plane difference, P, of 0.0039 inches. The warp and shute configurations in the woven condition were similar to those of FIGS. **9–14.**

EXAMPLE 5

The extension of the fabric generally varies with the loom tension applied to the warps when the fabric is woven flat. Thus fabric according to Example 2 when woven in a 78 × 56 mesh at a loom tension of 250–260 grams per warp strand had an extension of 1.13 percent with a plane difference of 0.0040 inches, and when woven in a 79 × 53 mesh at 200–210 grams per warp strand had an extension of 1.3 percent and a plane difference of 0.0034 inches. Fabric according to Example 3 when woven in a 78 × 56 mesh at a warp tension of 280–290 grams per strand had an extension of 1.16 percent and a plane difference of 0.0034 inches. In general, the extension of the finished fabrics decreases with an increase in loom tension and the short knuckles of the shutes have a sharper configuration with more vertical side portions and a bight portion with a shorter radius of curvature.

It should now be pointed out that the materials used for the cross-direction strands of the Fourdrinier fabrics of this invention have a significantly lower modulus of elasticity in the woven and heat set condition than the prior art shute materials described above in references to FIGS. **3–8.** This distinction is set forth in the following Table **1.**

Table 1

Cross-Machine Strand Material	Modulus of Elasticity
Example 1	0.82×10^4psi/10%extension
Example 2	0.85×10^4psi/10%extension
Example 3	0.88×10^4psi/10%extension
Example 4	0.72×10^4psi/10%extension
FIGS. 3–4	1.78×10^4psi/10%extension
FIGS. 5–8	1.18×10^4psi/10%extension

The machine direction strands of the above fabrics had a higher modulus of elasticity (psi/10 percent extension) than the cross-machine strands, all measured at an extension at which their crimp was substantially removed: Example 1, 2.81×10^4 psi; Example 2, 3.02×10^4 psi; Example 3, 2.71×10^4 psi; and FIGS. 5–8 **3.56** $\times 10^4$ psi.

Examples 6–9 present width contraction data of Fourdrinier belts which were made from fabric woven flat and seamed to form the endless belt. Fabrics of Examples 6–8 are according to the present invention, while the fabric of Example 9 is typical prior art fabric. In each of the examples, the finished belts were woven in a 78 × 55 ± 2 mesh. The warp material was 0.20 mm in diameter and had an elongation of 20 percent in the unwoven condition. The fabrics were heat-set while on the loom at a temperature of 390°F.

EXAMPLE 6

This example utilizes the shute material of Example 1 with fabric woven under a warp tension of 190–210 grams per strand. The extension of the woven fabric was 1.05 percent. The width contraction of the belt was 0.111 percent.

EXAMPLE 7

The shute material of Example 2 was utilized to weave a fabric in which the warp strands were under a loom tension of 310 grams per strand. The extension of the finished belt was 1.08 percent. The width contraction of the belt was 0.081 percent.

EXAMPLE 8

The shute material of Example 3 was woven into fabric utilizing a warp tension of 350 grams per strand. The extension of the finished belt was 1.00 percent and the width contraction of the finished belt was 0.240 percent.

EXAMPLE 9

Shute material as typically used in prior art plastic Fourdrinier belts comprising a polyester monofilament having an elongation in the unwoven state of about 48 percent was woven into a fabric utilizing a warp tension of 350 grams per strand. The extension of the finished material averaged 1.35 percent, and the width contraction was 0.30 percent.

With the fabrics set forth in Examples 6–8, the configuration of the crimped shute and warp strands had substantially the same geometry as the strands illustrated in FIGS. 9–14.

EXAMPLE 10

The preceding examples have been single layer Fourdrinier belts, but the present invention may also be embodied in double layer belts. A belt of such construction is illustrated in FIG. **17** made in a 143 × 92 mesh in a so-called seven shed pattern (other patterns may be used), and it will be noted there are two layers of cross-direction or shute strands extending across the fabric. The machine direction strands and the cross-direction strands were both 0.20 mm in diameter. The warp material was the same as used in the previous examples, and the shute material was that of Example 1. This fabric was tested for abrasion resistance and coefficient of friction by rotating a ceramic cylinder against a sample of the fabric held under load and having applied to it a slurry of abrasive particles. The tension is held constant and the horsepower to drive the cylinder is measured, with the test continued until the samples are completely destroyed. The fabric of this example had an abrasion resistance that was 85 percent higher than the abrasion resistance of the same fabric construction made with the prior art shute of FIG. **3,** and there was a 20 percent reduction in its coefficient of friction. The fabric of this example was heat set off the loom at about 350°F.

Fourdrinier belts according to the present invention, as described above in Examples 1–8 and 10, are thus made from polyester machine direction or warp strands which have a low elongation in the unwoven state in the range of about 15–25 percent at break and polyester cross-direction or shute strands which have a high elongation in the unwoven state of at least about 90 percent at break, with from about 95 to 130 percent being an effective more specific range; in comparison, prior art cross-direction strand materials usually have an elongation in the range of 40 to 50 percent at break. In the woven and heat set condition, the cross-direction strands of the Fourdrinier fabrics of the present invention have a modulus of elasticity of less than about 0.95 × 10^4 psi per 10 percent extension, particularly in the range of about 0.55 to 0.90 × 10^4 psi per 10 percent extension. As disclosed above, the modulus of the shute materials in Examples 1–4 ranged from 0.72 to 0.88 × 10^4 psi per 10 percent extension, and the shute material of Example 4 when heat set off the loom at 375°F had a modulus of 0.55 × 10^4 psi per 10 percent extension. In comparison, prior art shute materials have a modulus of elasticity greater than 1.0, or particularly in the range of about 1.18 to 1.78 × 10^4 psi/10 percent extension and heat set condition. Polyester materials of the character utilized in the present invention are made from a general purpose industrial or tire cord grade polyester which can have an intrinsic viscosity from about 0.6 to 0.96, such as polyethylene terephthalate. The resin is extruded in melt form at about 300°C in a conventional extruder using melt spin pumps and spinnerettes, and quenched in a water bath; up to this stage, the manufacturing process is similar to that used for conventional polyesters for Fourdrinier fabrics. However, following this point, conventional polyesters utilize a high draw ratio of about 5:1 usually accomplished in two steps, with the first draw in hot air or hot water about 90°C and the second at about 6° higher followed by a shrinking step at about 225°C. In contrast, the shute materials of the present invention are drawn in hot water at 90°C at a lower draw ratio in the range of about 3.3:1 to provide a 50–70 gram draw tension in order to obtain drawing without neck-down, and the polyester is dried in warm air at 45°C.

In the woven condition, the cross-machine direction strands in the fabrics of the present invention develop a different knuckle configuration than the typical prior art cross-machine strands. This is best illustrated with reference to FIGS. **15** and **16,** wherein FIG. **15** shows a typical short shute knuckle, S, of the fabrics of Examples 1–8 together with several sections along the knuckle. It will be noted first of all that the knuckle is characterized as having relatively vertical side arm portions interconnected by a bight portion having a small radius of curvature. Examination of the woven strand shows there is considerable necking-down of the cross-sectional shape of the strand in portions of the knuckle. This is further illustrated by the sections A–D shown in connection with FIG. **15** wherein it will be noted that the strand progresses from a round cross-section through flattened or elliptical cross sections until it reaches its most flattened condition at the top of the short knuckle as shown by Section D. FIG. **16** illustrates a short knuckle, S, in a cross machine strand of a fabric as described above with reference to FIGS. **3** and **4.** This knuckle has side arm portions having a greater degree of slope than the knuckle of FIG. **15,** and which are connected by a bight portion that has a relatively larger radius of curvature in comparison to the corresponding bight of the knuckle of FIG. **15.** The cross sectional views E–H in connection with FIG. **16** show that the strand progresses from a round cross section as in section E through elliptical sections which have a greater degree of roundness than the corresponding sections in the knuckle of FIG. **15.** (The sectional views of FIGS. **15** and **16** were taken from photomicrographs of a straightened woven strand, but they are representative of the final product.) It can be seen that the shute of FIG. 15 has very severe distortion of cross-section in the vicinity of the short knuckle, but the conventional shute of FIG. 16 has a much lesser degree of such distortion. The degree of distortion can be measured roughly by the ratio of the longest to the shortest axis of the most deformed sections, and it has been computed that this ellipticity ratio was about 2.1 for the shute of FIG. 15, but only about 1.5 for that of FIG. 16. Turning again to FIG. 15, it will also be noted that while the shute flattens along its outer surface at section B, it flattens on its opposite or inner surface at section D. as it passes over the warp. That the knuckles of the fabrics of Examples 1–8 are sharper than those of FIGS. 3 and 4 is further shown by the plane difference, P. As P increases, the shute extends further beyond a warp, hence indicating a more sharply defined knuckle geometry. The following Table 2 illustrates this change in P.

Table 2

Fabric	Plane Difference, P.	% Increase in P[1]
FIG. 3	0.0031 inches	—
Example 1	0.0044 inches	42%
Example 2	0.044 inches	42%
Example 3	0.0038 inches	23%

[1]measured relative to P of the fabric of FIG. 3.

It is believed that the unique knuckle geometry obtained with the cross-direction strands in accordance with this invention yields the reduced extension under load, the diminished width contraction and other useful characteristics of the Fourdrinier belts herein disclosed.

Fourdrinier belts according to the present invention can be made in any of the weaves and mesh size ranges typically used for Fourdrinier papermaking machines. The machine direction and cross-direction strands can vary in diameter and type (i.e. monofilaments, twisted yarns, etc.), and double layer Fourdrinier belts can also be made in addition to the single layer belts, as illustrated in the drawings. Successful Fourdrinier belts according to the present invention have been made in a range of sizes; for example, belts from 136 inches to 270 inches wide have been made, designed for papermaking machines operating at speeds of 1500 to 2700 feet per minute, utilizing machine direction strands having a diameter ranging from 0.17 to 0.30 mm and cross-machine direction strands ranging from 0.20 to 0.35 mm in diameter. The fabrics may typically range from about 40 to 100 mesh and the shute strands may typically range from about 0.125 to 0.45 mm in diameter.

Fourdrinier belts according to the present invention exhibit a number of significant advantages which accrue to the advantage of both the manufacturer of the belt and the papermaker who must use it on a machine. The manufacturer is able to produce a Fourdrinier belt which has a low percentage of machine direction extension and low width contraction and is able to do so while operating his looms at warp tensions that are well within the mechanical limitations of the looms. This can prevent overstressing and damage to the looms. The manufacturer is able to obtain a Fourdrinier cloth with these desirable characteristics while still maintaining a fabric construction utilizing a warp which has sufficient crimp to form a seamable material, thereby enabling the manufacture of belts from flat woven fabric.

On the other hand, the present invention also lends itself to manufacture of the belt woven in the endless loop condition. Further, the manufacturer of the Fourdrinier belts is able to obtain a desirable type of cloth without resorting to off-loom heat setting; thereby obviating the extra apparatus and handling associated with such technique. Instead, they can produce an equivalent cloth using on-loom heat setting. Naturally, however, the present fabrics can also be made with off-loom heat set treatment if so desired. A further advantage is that wide Fourdrinier fabrics can be woven flat on a loom utilizing on-loom heat setting so that it is not necessary to make a cloth 20 to 30 percent wider than its finished width, thereby significantly increasing the capacity of existing looms to make the Fourdrinier belts suitable for wide papermaking machines.

The reduction in extension possible with the Fourdrinier belts as herein described is best demonstrated by comparison of the extension data for the fabrics of Examples 1–3 with that of the prior art fabrics of FIGS. 3–4 as set forth below in Table 3.

Table 3

Fabric	Extension	% decrease in extension[1]
FIGS. 3–4	1.36%	—
Example 1	1.02%	25%
Example 2	1.02%	25%
Example 3	1.11%	18%

[1]determined in comparison to extension of fabric of FIGS. 3–4.

Additionally, it should be noted that the extension of the fabrics of Examples 1–3 is equal to or less than the extension of the off-loom heat set fabric of FIGS. 5–8 (which was 1.1 percent).

The improvement in width contraction attainable with the present fabrics using on-loom heat setting is shown in Table 4.

Table 4

Belt	Width Contraction	% Reduction in Width Contraction[1]
Example 9	0.30%	—
Example 6	0.11%	63%
Example 7	0.081%	73%
Example 8	0.240%	20%

[1]determined in relation to width contraction of belt of Example 9

The foregoing reduction in width contraction with the belts of Examples 6–8 is significant and allows the use of such belts on papermaking machines without the need to also use a bowd roll or similar additional apparatus. Further, the present fabrics allow the use of the on-loom heat set treatment technique to provide fabrics that have the width contraction characteristic of an off-loom heat set material; thus, the belts of Examples 6 and 7 in particular have a width contraction on the same order, or less in some instances, of a fabric that underwent off-loom heat setting.

The above advantages further provide a Fourdrinier belt which has an increased running life in that it can be maintained on the papermaking machine for a longer time before replacement. This is of interest to the paper manufacturer because of reduced expenses with respect to the belt and of the reduction in the loss of machine down time necessitated by the change of a belt. Thus, the increased plane difference, P, reported above in Table 2 means that more of the shute knuckle is available to take the wear before reaching the warp knuckles. The plane difference, P, as reported herein, is on the wear surface of the papermaking belt which travels over the various rollers, suction boxes, and other equipment associated with the papermaking machine. As one example, a 54 × 38 mesh belt that was 177 inches wide and 128 feet long was installed on a Kraft papermaking machine and operated at 2,000 feet per minute.

The belt was made with 0.30 mm. diameter warp and 0.35 diameter shute of the same materials used in Example 1, and in the same weave; it had an extension of 0.86 percent and a width contraction of 0.109 percent. The average life of a prior art belt as of FIGS. 3–4 on the machine had been 35 days, but the belt according to the present invention ran 70 days before there was a machine malfunction which ruined the belt, but there was no malfunction of the belt itself. Laboratory analysis of the belt at the end of the 70 days indicated that 41 percent of the belt remained for running, and it was further estimated that the belt would have run over 100 days if it had not been damaged by the machine. In a second example, a 78 × 52 mesh belt with a 0.20 mm. diameter warp and 0.25 mm. diameter shute according to FIGS. **3–4** was installed on a machine and operated for 60 days before being worn out. In contrast, a belt of the same structure utilizing shute material as in Example 1 was installed on the same machine and operated for 121 days before removal, which doubled the life in this particular installation; the belt had an extension of 1.2 percent and a width contraction of 0.111 percent.

The reduction in coefficient of friction and increase in abrasion resistance of the double layer fabric of Example 10 indicates additional advantages of a Fourdrinier belt made according to this invention. These results were not predicted, and it is felt they presage advantages in addition to those of dimensional stability and others as discussed previously. A further example of additional utility is indicated by the following: A Fourdrinier fabric in a full twill weave (in which each shute passes over two warps and then under the next two warps) was woven using the conventional polyester monofilament as in the fabrics of FIGS. **3–4** in a 55 × 36 mesh using 0.30 mm. warp and 0.35 mm. shute strands. The fabric was unsatisfactory for its intended use because it had an extension of 1.14 percent and the warp knuckles on the wear side protruded beyond the shute knuckles a distance of 0.0024 inch, so that they had to take the wear of the fabric instead of the shute knuckles which is the more desirable condition. The same fabric was woven with a shute of a polyester of this invention having an elongation of about 105–110 percent in the same mesh using 0.27 mm. warp and 0.35 mm. shute, woven with a warp tension of 600 grams/strand. The resulting fabric had an extension of only 0.80 percent. Furthermore, and most importantly, the shute knuckle of this fabric of the present invention protruded beyond the warp knuckles on the wear side to have a plane difference, P, of 0.0031 inch; thus, there was a complete shift of the wear of the cloth to the shute knuckles instead of the warp knuckles taking the wear as in the above fabric. Even though it used a smaller size warp strand, the fabric was a substantial improvement and makes it possible to offer a commercially acceptable fabric of this weave so that, in this instance, the present invention provided a useful Fourdrinier fabric which had not been previously attainable.

The foregoing detailed description has thus set forth new woven Fourdrinier belts made from machine direction strands and cross-machine direction strands of heat-set synthetic plastic material wherein the cross-machine direction strands are monofilaments of a polyester synthetic plastic material having a modulus of elasticity of less than about 0.95×10^4 psi per 10 percent extension, and the machine direction strands are monofilaments of a polyester material weavable with the cross-direction strands and having a modulus of elasticity greater than about 1.0×10^4 psi per 10 percent extension. The modulus of elasticity is measured as defined hereinabove on the woven heat-set strands after they have been straightened from their crimped condition. A particular range for the modulus of the cross-direction strands disclosed is from about 0.55 to 0.90×10^4 psi/10 percent extension. The modulus of elasticity of the machine direction strands is to be greater than that of the cross-machine direction strands, particularly greater than about 1.0×10^4 psi/10 percent extension. Machine direction strands with moduli in the range of about 2.71 to 3.56×10^4 psi/10 percent extension are shown in connection with Table 1, although machine direction strands with moduli above and below such range are considered useful with the disclosed fabrics. It is presently expected that there is a ± 5 percent range of error in the modulus data as reported herein, and the term "about" is used in reference to such numerical data to refer to such experimental error; all modulus data is measured at an extension of a woven heat-set strand after it has just been straightened to remove any crimp in it. The Fourdrinier belt may be woven in any of the weaves used in the Fourdrinier art, and can be made in single layer and double layer (i.e. two layers of cross-machine direction strands) constructions.

We claim:

1. A woven Fourdrinier papermaking belt made of machine direction and cross-machine direction strands of heat-set synthetic plastic monofilament material, comprising the combination of:

1. cross-machine direction strands of synthetic polyester material having, in their woven and heat-set condition, a modulus of elasticity of less than about 0.95×10^4 psi per 10 percent extension, measured as herein defined; and
2. machine direction strands of synthetic polyester material weavable with the cross-machine direction strands and having, in their woven and heat-set condition, a modulus of elasticity greater than about 1.0×10^4 psi per 10 percent extension measured as herein defined.

2. A Fourdrinier papermaking belt according to claim **1** wherein:

the cross-machine direction strands have a modulus of elasticity in the range of about 0.55 to 0.90×10^4 psi per 10 percent extension.

3. A Fourdrinier papermaking belt according to claim **1**, wherein: the cross-machine direction strands have a modulus of elasticity of about 0.82×10^4 psi per 10 percent extension.

4. A Fourdrinier papermaking belt according to claim **1**, wherein: the cross-machine direction strands have a modulus of elasticity of about 0.85×10^4 psi per 10 percent extension.

5. A Fourdrinier papermaking belt according to claim 1, wherein: the cross-machine direction strands have a modulus of elasticity of about 0.88×10^4 psi per 10 percent extension.

6. A Fourdrinier papermaking belt according to claim 1, wherein: the cross-machine direction strands have a modulus of elasticity of about 0.72×10^4 psi per 10 percent extension.

7. A woven Fourdrinier papermaking belt made of machine direction and cross-machine direction strands of heat-set synthetic plastic monofilament material, comprising the combination of:

1. cross-machine direction strands of synthetic polyester material having an elongation at break of at least about 90 percent in their non-woven and non-heat set condition, and further having a modulus of elasticity of less than about 0.95×10^4 psi per 10 percent extension in their woven and heat-set condition, both the elongation and modulus measured as herein defined and
2. machine direction strands of synthetic polyester material weavable with the cross-machine direction strands and having, in their woven and heat-set condition, a modulus of elasticity greater than about 1.0×10^4 psi per 10 percent extension measured as herein defined.

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