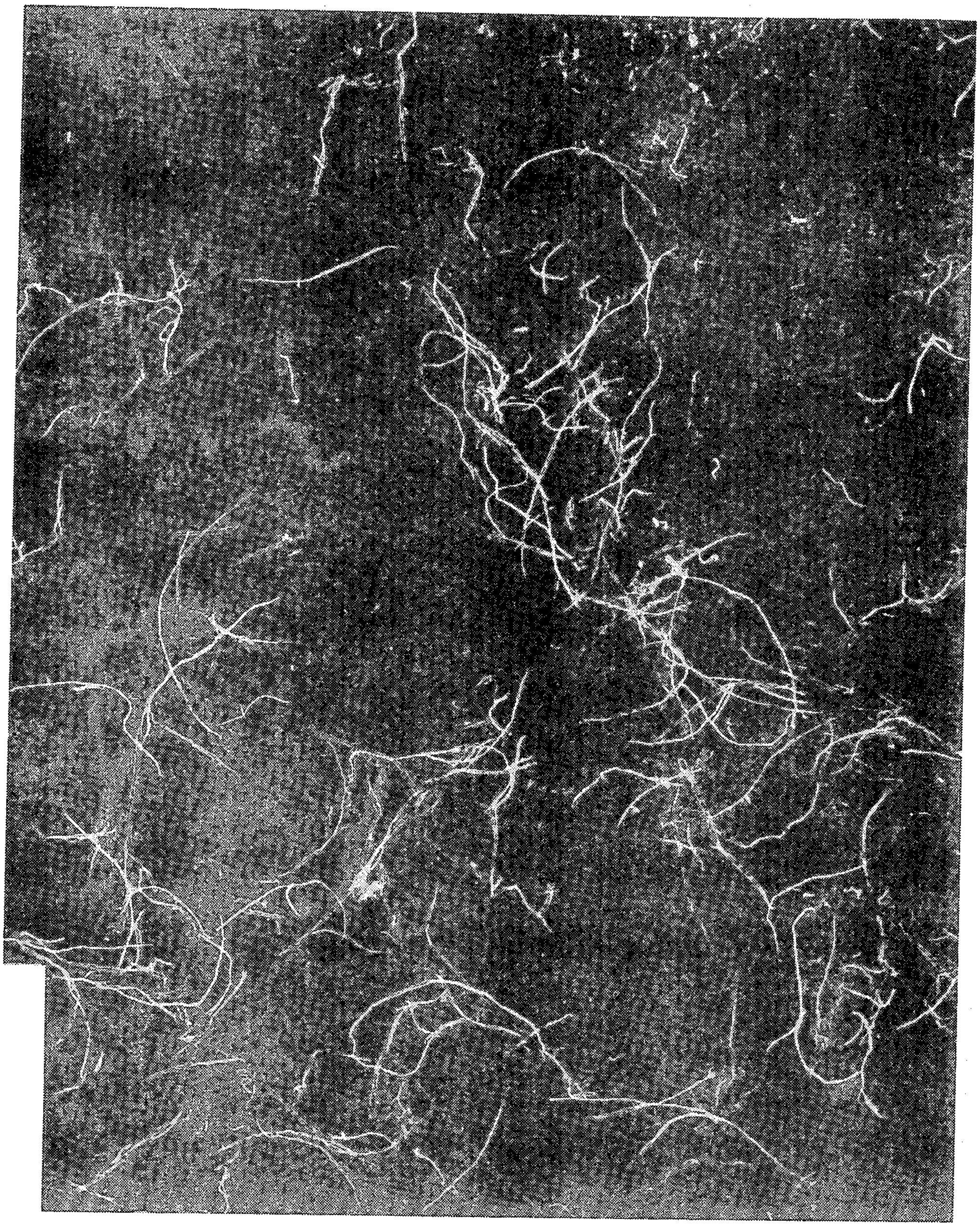

FIG-1

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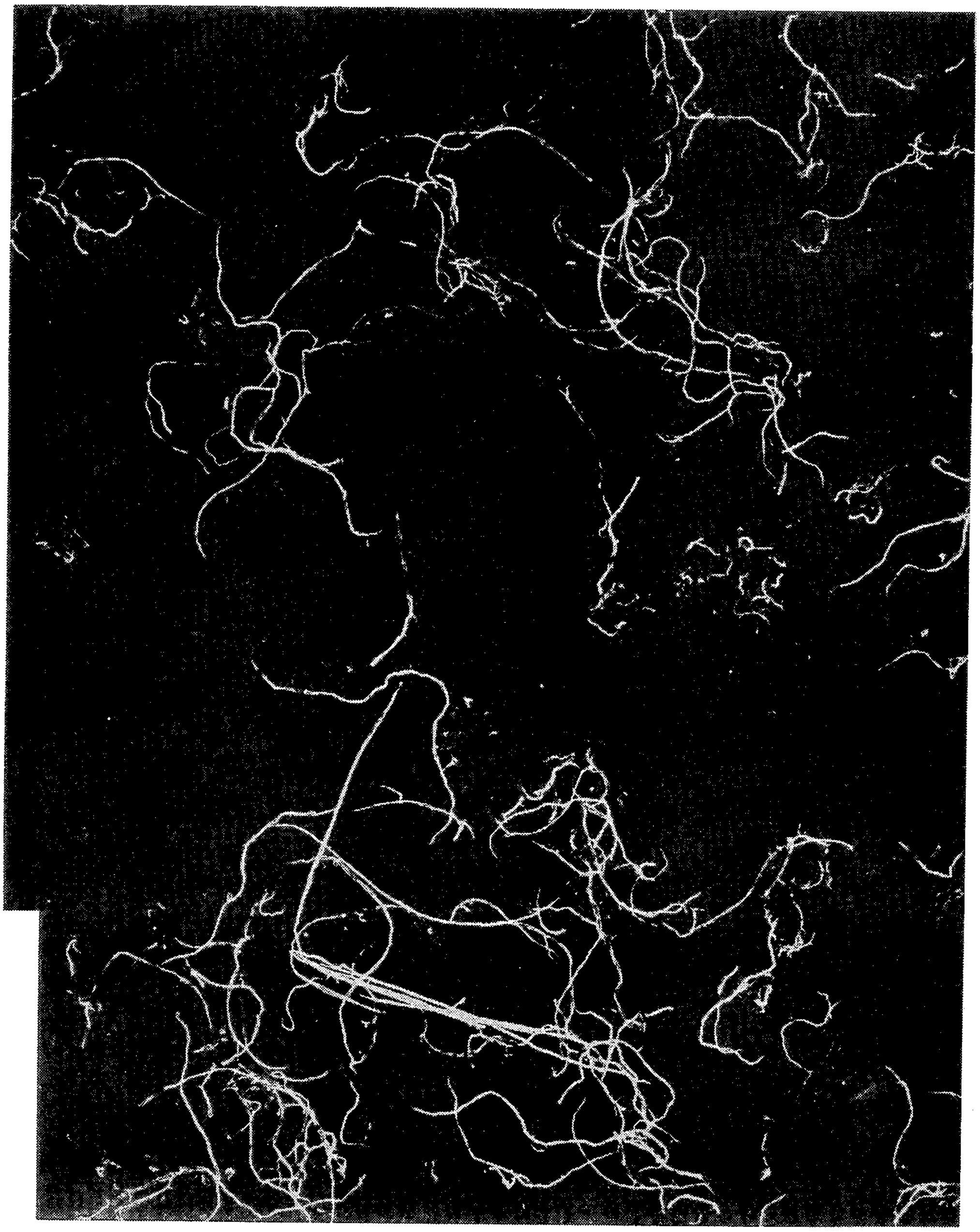

FIG. 2

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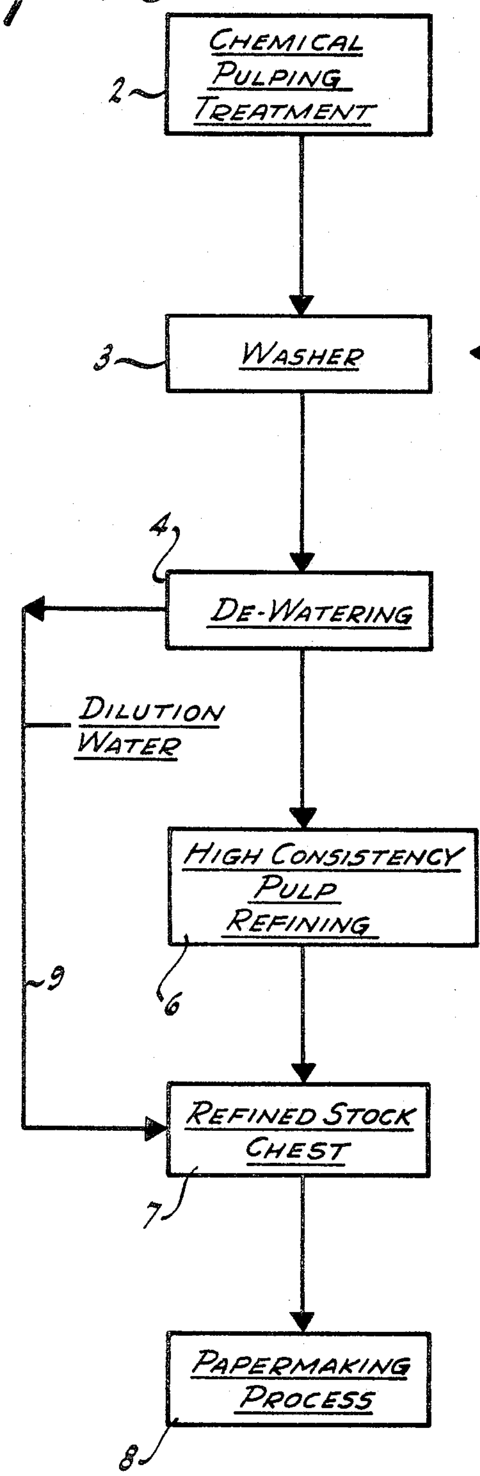
PROCESS FOR FIBRILLATING CELLULOSIC FIBERS AND PRODUCTS THEREOF

Original Filed Feb. 25, 1964 4 Sheets-Sheet 3

FIG-3



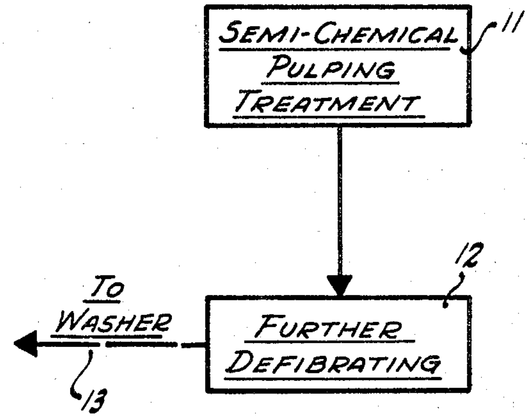


FIG-4

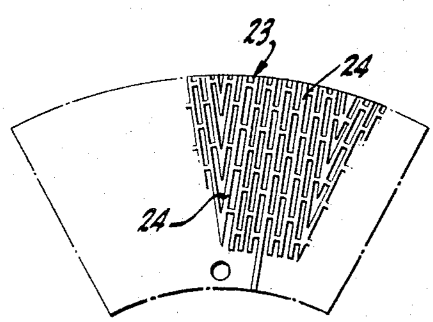


FIG-6

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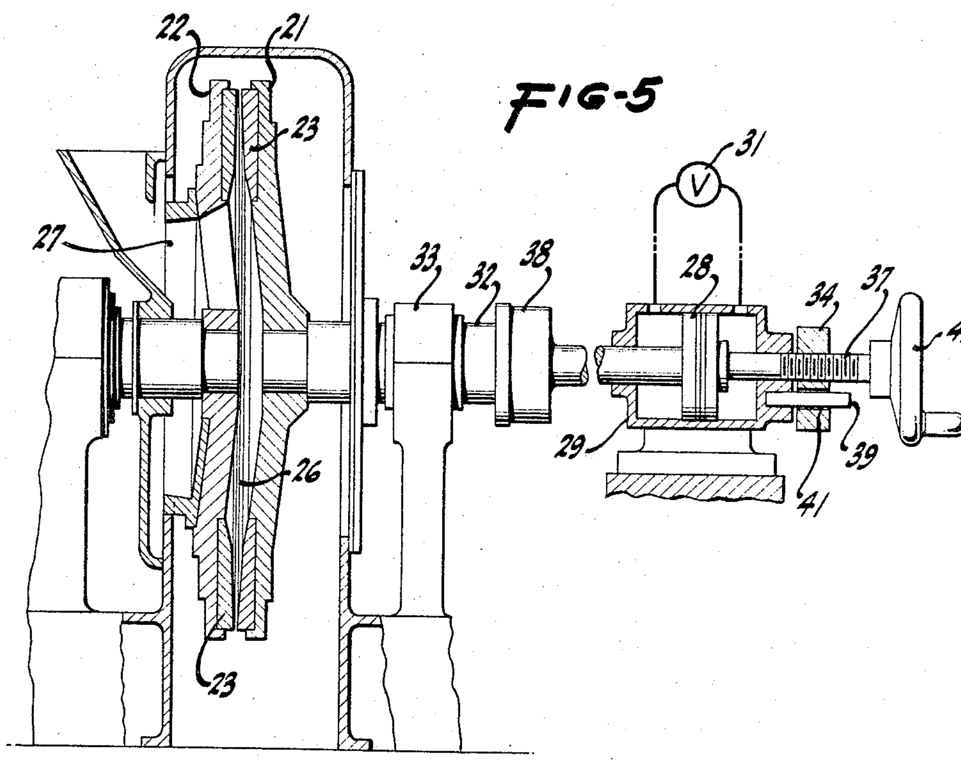

FIG-5

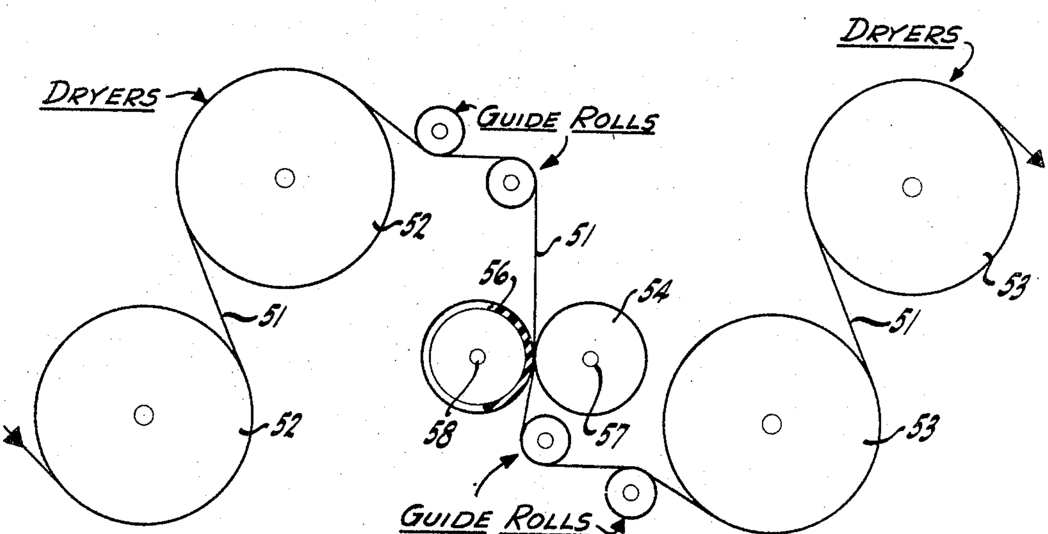

FIG-7

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PROCESS FOR FIBRILLATING CELLULOSIC FIBERS AND PRODUCTS THEREOF

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Continuation of application Ser. No. 347,231, Feb. 25, 1964. This application Dec. 30, 1966, Ser. No. 606,446

11 Claims. (Cl. 162—28)

ABSTRACT OF THE DISCLOSURE

Cellulosic high consistency papermaking pulp in the form of a semi-solid, non-flowable and non-pumpable lumpy mass composed of previously defibered fibers is continuously refined by continuous passage through a refining space comprising opposed disc-like working surfaces relatively rotatable about a common axis wherein the pulp is continuously maintained packed under high compression to cause fibrillation by inter-fiber friction along the surfaces of the individual separated fibers without substantially fracturing the same.

The instant application is a continuation of Ser. No. 347,231 filed Feb. 25, 1964, now abandoned which is a continuation-in-part of applicants' copending applications, Ser. Nos. 230,290 and 230,291, both filed Oct. 12, 1962, and now abandoned; the disclosures of which being combined herein.

This invention relates to papermaking pulps, paper produced therefrom and to a process of making the same. More specifically, it relates to a mechanical refining treatment of defibered cellulosic pulps to produce an improved pulp product for the production of paper characterized by high strength properties.

Mechanical treatment of cellulosic pulps before they are made into paper is well known in the pulp and paper industry. The procedure ordinarily employed in the industry involves passing a low-consistency pulp, i.e., a pumpable pulp in slush form, usually at a consistency (percent by weight of solid fibers in water) of from about 0.5% to about 5%, through a conventional pulp beating or refining apparatus, such as a beater, jordan, Morden and, less frequently, a disc refiner. The pulp fibers which are beaten or refined in such manner usually develop certain strength properties when made into paper, primarily tensile and bursting strength, but lose their original tearing strength, due to a vigorous fracturing action, namely, a bruising, crushing, or cutting action exerted by the pulp refining equipment on low-consistency pulp. This is so because such refining at low-consistency requires that the refining elements break down the pulp fibers by physical impact therein, in the nature of a chopping effect. Also, freeness, namely, the drainage rate of water through the fiber mat on the papermaking machine, is reduced but this does not materially affect strength.

As a result of the passage of a low-consistency aqueous fiber suspension between the metallic elements of beaters or refiners, which in the operation of low-consistency refining necessarily are arranged to work through contact against each other, the structure of the pulp fibers is mutilated by fracturing their walls, decreasing their length, forming fibrils primarily as a result of rupturing or fracturing the fibers, splitting, etc., in various degrees depending on the type of the apparatus employed and conditions applied thereto. Moreover, due to the relatively large amount of water with consequent fluid nature of the low-consistency fibrous pulp, a non-uniform mechanical treatment frequently results. This is due to the fact that the large water content acts as a fluid conveying means which

carries some fibers through the refiner without being subjected to a refining action, and there is very little, if any, inter-fiber friction. Thus, some fibers pass through the beating or refining equipment virtually untouched, while other fibers may receive excessive rupturing or fracturing treatment.

A more recent development in processing of wood pulp, as exemplified in U.S. Patents Nos. 2,516,384, 2,561,013, and 3,028,632, has been a process of rolling and curling pulp fibers. Such a process consists of forming small nodules or ball-like particles of fibers and subjecting the nodules to a gyratory movement between two opposed working elements which compress the nodules during their passage therebetween. The properties of the resulting pulp are different from those produced by the low-consistency beating or refining procedures discussed hereinabove. The pulp curling treatment produces a decrease of burst and tensile strength in the resultant paper and in increase of tear and stretch, while the pulp freeness remains unchanged and frequently is slightly increased. Furthermore, in order to insure the necessary rotation of pulp nodules, the relative tangential velocity of the working elements, in other words, the relative peripheral velocity, employed in the curling process must be maintained at a low level, usually in the range of 50 to 300 feet per minute, and the power requirements of the process are unusually low as compared to conventional pulp refining procedures.

Whereas various modifications of strength properties of cellulosic pulps have been realized by the known mechanical procedures, it has not been possible heretofore to process a defibered pulp in such a manner as to increase the most important strength properties of paper made therefrom. i.e., burst and tensile strength, tear, toughness and stretch, particularly cross machine direction stretch (C.M.D.) on a papermaking machine, all simultaneously.

Accordingly, it is the general object of the present invention to provide an improved process of producing high strength papermaking pulp having physical characteristics superior to those of conventional pulps.

Another object is the provision of a novel papermaking pulp which is characterized by imparting increased burst, tensile, tear, stretch and toughness properties to paper made therefrom, as compared to paper from the same untreated pulp.

A further object is to provide an improved process of refining a papermaking pulp at high-consistency under controlled operating conditions, whereby a pulp is provided imparting increased over-all strength and bonding properties to paper converted therefrom.

Another object is the provision of a high strength extensible paper characterized by having substantially isotropic stretch while having other physical characteristics superior to those of other extensible papers.

Still another object is the provision of a novel high strength paper characterized by substantially isotropic toughness and increased stretch and tear strengths.

Other objects and advantages of the invention will be apparent from the following description with reference to the accompanying drawings, wherein:

FIG. 1 is a reproduction of a microphotograph of fibers in a conventional low-consistency refined pulp;

FIG. 2 is a similar reproduction of a microphotograph of fibers in high-consistency refined pulp produced in accordance with this invention, and illustrating the difference of such fibers by comparison with FIG. 1;

FIG. 3 is a schematic view in block form illustrating a process flow sheet in which high-consistency pulp refining is employed on chemically treated pulp which causes substantially all of the lignin to be removed from the fibers;

FIG. 4 is a similar schematic flow sheet of a semi-chemical pulping treatment wherein the fiber is partially delignified; the dotted line indicating subsequent treatment of material after the first two-steps shown in FIG. 4;

FIG. 5 is a schematic view partially in section illustrating a well known type of commercial pulp refiner which is advantageously employed in the high-consistency pulp refining process hereof;

FIG. 6 is a fragmentary plan view of a conventional refining plate section employed in the refiner, and illustrating a roughened surface thereon; the dotted lines in the view indicating the complete plate section; and

FIG. 7 is a schematic view illustrating a location of creping apparatus in the drying section area of a papermaking machine, for effecting creping of paper formed from the high-consistency pulp hereof, to impart isotropic stretch and toughness to the paper.

In general, cellulosic fiber is formed of many layers of fibrils bound together and having an outer relatively hard primary wall and an outer lignin lamella. Physical separation of the fibers is known as defibrating. In chemical treatment of the fibers, as explained more fully hereinafter, substantially all of the lignin is separated so that it can be readily removed by subsequent washing. In semi-chemical treatment, only a portion of the lignin is separated from the fibers, and can be removed by subsequent washing. Therefore, semi-chemical treatment is usually followed by a mechanical defibrating step.

The invention hereof is particularly advantageous with at least partially chemically treated pulp, and desirably full chemically treated pulp because the lignin removal, particularly the outer lignin lamella, enhances refining at high pulp consistency since exposure of the outer primary cellulosic wall facilitates fibrillation of the fibers by inter-fiber friction in a manner which will be discussed later. However, the invention is applicable to procedures wherein defibration of cellulosic fiber is effected solely by mechanical means but it is not as effective.

High-strength papermaking pulp, according to this invention is produced by first providing a high-consistency, substantially defibered pulp containing separated cellulose fibers; the consistency being such that the defibered pulp is a non-fluid or semi-solid mass desirably of non-pumpable character, and formed of discrete lumpy particles in which the fibers are in intimate contact. The pulp is introduced into a working space formed between two opposed roughened surfaces which are in relatively high motion relative to each other and which are spaced and maintained apart by a distance not less and desirably greater than the thickness of the individual fibers introduced therein. The spacing is important because in the high-consistency refining hereof, it is critical that the roughened surfaces do not materially fracture, chop or cut the fibers for reasons explained hereinafter. Such roughened surfaces in high-consistency refining act primarily to impart motion to the fibers between such surfaces so that inter-fiber friction, namely, rubbing between individual fibers, can occur to effect the desired refining by attrition of the fibers against themselves. Consequently, the roughened surfaces can be of any character as long as they serve this purpose.

In this connection, the refiner surfaces are operated at sufficient relative tangential velocity and sufficient power input to maintain such inter-fiber friction. This inter-fiber action results in fibrillation of the fibers, namely, the freeing of extremely fine hair-like strands projecting from the surface of each individual fiber filament without substantially cutting or fracturing them, while the pulp fibers move rapidly and continuously in a single path, as explained more fully hereinafter, through the space between the refining surfaces in a direction away from the point of their introduction toward the point of their discharge.

The pulp treated mechanically in such manner is discharged continuously from the above mentioned refining

space. The treated pulp, which has substantially the same consistency as before the treatment, has widely different properties than the same pulp in the untreated form. Thus, when formed into paper the principal physical strength properties of the paper, namely, burst, tensile, tear, stretch and toughness are increased, while freeness of the pulp is decreased. Moreover, the bonding strength of the treated fibers formed into paper also is significantly improved. In the manufacture of paper, the resulting high-consistency pulp is diluted to the conventional low papermaking consistency and formed into a paper web. After refining, the high-consistency pulp also may be further dewatered to a consistency suitable for shipping or storage.

In this connection, after leaving the refiner, the high-consistency pulp is quite hot because of the interfiber friction. Therefore, if the pulp is to be further dewatered for shipment or storage, it is desirable first to dilute it with water to any suitable consistency which will cool the pulp and also enable it to be conveyed by pumps. Then it can be dewatered by any suitable means, such as a press, to the shipping or storage consistency desired.

Cellulosic material which is suitable for use as a starting material in accordance with this invention may be derived from any species of coniferous pulpwood, such as spruce, hemlock, fir, pine and others; deciduous pulpwood such as poplar, birch, cottonwood, alder and others; as well as from fibrous, non-woody plants suitable for papermaking, such as cereal straws, bagasse, cornstalks, grasses, and the like, and also the usual waste cellulosic sources.

These various fibrous raw materials may be converted into pulp by way of the conventional pulping procedures during which the material is digested with an aqueous cooking liquor containing the selected pulping agent. The conventionally employed alkaline pulping liquors, such as kraft and soda; acid liquors, such as sulfite or bisulfite; and neutral sulfite and other well known pulping liquors are exemplary. As previously related, such pulping treatments are known in the industry as chemical pulping which results in substantially complete removal of all the lignin layer, and the invention hereof is particularly advantageous with chemical pulping.

A flow sheet for high-consistency refining with chemical pulping is shown in FIG. 3, wherein the cellulosic fiber is chemically treated in a conventional manner at **2**, and is removed or blown at any suitable consistency, preferably about 10 to 14%, to washer **3** of any conventional construction wherein chemicals and separated lignin are removed. From washer **3**, the material is then removed at about a 3% to 16% consistency, to any suitable dewatering means **4** which may be a vacuum thickener or a screw or piston type press. Sufficient water is removed at **4** to provide a desired high-consistency pulp as explained later; and the high-consistency pulp is then introduced into high-consistency mechanical refiner **6**. From the refiner, the pulp is conducted to a refined stock chest **7** wherein the pulp is diluted to paper forming consistency, from which the diluted pulp is conducted to the papermaking machine indicated at **8** which may be a Fourdrinier or cylinder type machine. Water from the dewatering apparatus **4** is conducted to chest **7**, as indicated by flow line **9**, to supply dilution water.

Semi-chemical pulps which are produced by cooking wood chips to a high pulp yield usually followed by mechanical defibering also are advantageously employed as a starting material in the process of this invention because of partial removal of lignin. As illustrated in FIG. 4, semi-chemical pulp is further defibered after it has been treated at **11** by any suitable mechanical defibrator **12** which frees the fiber but does not refine the same. From defibrator **12**, the defibrated pulp is conducted to a washer as indicated by dotted line **13** and the remainder of the process for high-consistency refining is the same as shown in FIG. 3.

Suitable pulp for the practice of this invention may also be derived by grinding mechanically or defibering a fibrous lignocellulose material to produce the so-called mechanical pulp. However, mechanical pulp is not as desirable for high-consistency refining, as at least partially chemically treated pulp, namely, chemical and semi-chemical pulp, because of large amounts of lignin present.

From the preceding, it is seen that all of the aforementioned pulp sources are substantially defibered before being subjected to the high-consistency refining treatment according to this invention, so that a pulp containing separate individual fibers is provided as a result of the subsequent high-consistency refining. The foregoing pulp sources may be employed either singly or in admixture with each other and may be subjected to a preliminary conventional bleaching step if it is desired to produce a pulp of increased brightness. Also, the pulp coming directly from either chemical, semi-chemical or mechanical operations, is of lower consistency than required for high-consistency refining. In order to render such low consistency pulp suitable for processing according to this invention, it may, if necessary, be subjected to a screening operation prior to dewatering in order to remove large size uncooked or undefibered particles.

In general, the dewatering of the pulp after defibration, to increase its consistency to a level where it forms a semi-solid, non-flowable, moist mass adapted for high-consistency defining, is to a pulp consistency in the range of between about 10% and about 60% with the fibers in intimate contact; preferably between about 20% and 35% is satisfactory. If the consistency is much below 10%, the high amount of water may act as a lubricant preventing the desired refining by inter-fiber friction. If much greater than 60%, the pulp will be too dry which may result in burning under the inter-fiber friction. Moreover, some water is required for lubrication purposes to prevent undue excessive friction between the fibers which might cause excessive fiber damage. The about 20 to 35% consistency range has been found most advantageous for obtaining optimum results. After the dewatering, the resulting moist, high-consistency but still unrefined pulp may be shredded or otherwise divided into particulate relatively small lumps in order to facilitate its further processing.

The high-consistency substantially defibered pulp is fed into a refiner which will effect the aforementioned inter-fiber friction, preferably by metering, such as by a screw conveyor, into a suitable refining apparatus, such as a conventional single disc refiner, a double disc refiner, or a conical type refiner adapted for handling a high-consistency pulp. Any of the above mentioned machines desirably have two opposed surfaces which are spaced apart and moving relative to one another. Thus, in the case of single disc refiners or conical type refiners, one of the surfaces is stationary while the other one is rotating; in the case of double disc refiners, both surfaces are rotating either in the same or in opposite directions. Any of the above mentioned surfaces should, however, be moving with sufficiently high relative tangential velocity as to insure that pulp fibers will move rapidly and continuously in a single path, as opposed to a gyratory or rolling movement, from the point of their introduction toward the point of their discharge.

The term "single path" describing the motion of the pulp fibers in accordance with this invention denotes a substantially continuous uninterrupted forward and non-retrogressive motion from the inlet of the pulp into the refiner to its discharge. For instance, a relatively straight line movement occurs in the case of double disc refiners in which the discs rotate in opposite directions at the same speed, a spiral movement in the same plane in the case of single disc refiners, and a spiral movement in different planes, like the threads of a screw, when a conical type refiner is employed. In any event, the relative motion of the refining elements should be such as described more fully later, as to cause the individual fibers to become fibrillated essentially by inter-fiber friction, without substantial cutting, rupturing, or substantial balling of the fibers into nodules. Also, the working space between the refining elements is maintained packed with the high-consistency pulp to provide a pad of pulp between such surfaces with the fibers all in intimate contact to enable the inter-fiber friction.

The relative movement between the two surfaces will vary depending upon the type of apparatus employed. In general, the surfaces should operate at a relative tangential velocity of no less than about 1000 feet per minute, and the rotation should be about a fixed axis to obviate relative gyratory movement which results in balling of the fiber. When one of the surfaces is stationary, the relative tangential velocity of the surfaces should preferably be at least 5000 feet per minute, and in the case where both surfaces are moving in opposite directions, the relative tangential velocity of at least 15,000 feet per minute is preferred. Under all circumstances, the velocity should be sufficiently great for any given spacing between the refining surfaces as to impart sufficient energy to the fibers to effect attrition therebetween and the fibrillation essentially by the inter-fiber friction, and at the same time provide sufficient energy to move the fibers through the refiner. The two surfaces between which the pulp is treated should as previously related be roughened by having a set of ducts, grooves, indentations, or other projections of such character as to engage the high-consistency pulp.

FIGS. 5 and 6 illustrate schematically the particular type of double disc refiner which has been found to be most advantageous for the high-consistency refining hereof. This refiner is essentially the same in principle as disclosed in U.S. Patents Nos. 2,214,707 and 2,568,783, and is known in the industry as the Bauer 411.

It comprises a pair of refining discs **21** and **22** carrying removably mounted roughened surface refining plate sections **23** as shown in FIG. 6; the roughened surface being formed by ribs **24**. The rib pattern shown in FIG. 6 is one of many different patterns that are available, and is merely shown for purposes of illustration. The working space **26** between the discs is usually tapered toward the periphery; and in the usual manner, pulp to be refined is introduced by any suitable means into the working space **26** through inlet **27** adjacent the axis of rotation of the discs. These discs are rotatable about a fixed common axis in opposite directions and at the same velocity by suitable power means, and since they rotate about a fixed axis they do not effect gyratory movement.

One of the discs, namely, disc **22** at the left of FIG. 5 is rotatable in a fixed plane, while the other disc **21** is yieldably mounted for slight movement along the axis of rotation of the disc, but the movement thereof is limited toward the other disc; and the minimum spacing between the discs can be adjusted. As shown in FIG. 5, the yieldable mounting of disc **21** is permitted by a hydraulic piston **28** slidable in cylinder **29** into which hydraulic fluid can be introduced on either side of the piston in a well known manner through hydraulic valve control mechanism **31**; the fluid in cylinder **29** acting as a yieldable resilient cushion. Some machines employ springs for such purpose. At one end, the left appearing in FIG. 5, the piston is connected to a rod **32**, slidable in bearing **33** and attached to disc **21**. The limit of movement of yieldable disc **21** toward disc **22** is controlled by a stop nut **34** threaded on spindle **37** having a swivel connection at **38** with rod **32**; nut **34** being prevented from turning by means of a pin **39** projecting through an aperture **41** in the nut. By turning hand wheel **42** secured to spindle **37**, the relative axial position of nut **34** with respect to spindle **37** can be adjusted to limit the forward movement of disc **21** and thus provide control for the minimum spacing between discs **21** and **22**.

In operation for high-consistency refining, the minimum spacing between the working elements or ribs **24** at the periphery of the discs is adjusted to be greater than the thickness of the fiber so as to obviate any substantial fracturing of the fibers. The maximum spacing is immaterial but it should be relatively close for practical purposes. All that is necessary is to feed the high-consistency pulp at such rate and with sufficient power input to maintain the working space **26** packed with a continuous flow of the pulp and provide a continuous pad of fiber in the working space between the working elements which form such space, so that as the fibers pass through such space under a high velocity and pressure, they are worked solely by inter-fiber friction to effect the fibrillation. By observing the power input on a gage usually accompanying the machine, an operator can adjust the spacing as the refining proceeds to maintain the continuous pad in which the fibers are in intimate contact. Also, should there be any clashing of the roughened surfaces, which is readily discernible to the operator, he can immediately make an adjustment to obviate this, and consequent fiber fracturing. The axially yieldable mounting of disc **21** is advantageous in obviating overloading, which might injure the fiber.

It is desirable to enhance feeding of the high-consistency pulp into working space **26**, by maintaining a continuous flow of a slight amount of water through inlet **27**. Usually, the amount of water is such as not to decrease the consistency of the pulp to any material extent, preferably not more than about 3%. The water introduced is of such minor amount that it does not have any effect on the high-consistency refining of the pulp, and the consistency of the pulp entering between the refining surfaces is substantially the same as that discharged therefrom.

Summarizing, it is highly critical and important that sufficient clearance between the two working surfaces be provided so that substantially no cutting action occurs during the passage of the pulp therebetween, and that there be a sufficient quantity of pulp under compression between the discs, to enable the inter-fiber friction. Hence, the space between the two surfaces should be adjusted according to the type of pulp employed so that the distance between the surfaces will be greater than the thickness of the fibers being processed. Also, the space should be adjusted in accordance with the relative speed of movement of the discs and the rate of feed of the pulp to the refiner (pulp throughput).

The power input may also vary in accordance with the type of pulp being processed and with the refined pulp qualities desired. For example, with the pulp under compression in the working space between the refiner surfaces of the machine, in case of unbleached kraft pulp the amount of power applied for a single passage of pulp between the two refining surfaces should be in the range of between 10 and 60 H.P. days/air dry ton of pulp, namely, the daily total horsepower required to process one ton of pulp. Groundwood pulp will require a power input also in the range of between 10 and 60 H.P. days/air dry ton of pulp. Sulfite pulp will require a lower power input of between 3 and 30 H.P. days/air dry ton of pulp because of being a softer fiber and requiring less energy input; and chemical pulps derived from fibrous non-woody plants, such as baggase, will require a still relatively lower power input in the range of 1 to 20 H.P. days/air dry ton of pulp.

Regardless of power input, however, it is important to impart a motion to the surfaces under sufficient power input so as to insure a vigorous frictional contact among the fibers during their passage through the space formed by the two refiner surfaces, which at the same time exert a high compression on the fibers while they are being worked upon. Although the operating pressure of the refining surfaces on the pulp fibers may vary, in general in the Bauer 411, a pressure of between 5 to 20 pounds per square inch will be sufficient to produce a pulp of desired properties. The feed rate of the pulp into the space between the two surfaces (throughput) will depend on several conditions, including the type of pulp being processed, its consistency, the horsepower input, the type of apparatus employed and the clearance between the opposed surfaces. In general, the pulp feed rate at any given input horsepower and the refiner surface spacing, is adjusted in accordance with the quality of pulp desired.

Accordingly, it will be apparent that several factors discussed hereinabove are available for adjustment and control of the conditions so that the desired modification of the strength properties of the pulp processed in accordance with this invention is realized.

The fundamental principle of the mechanical treatment to which a papermaking pulp is subjected according to the invention is to cause rubbing and friction between the fibers, resulting in fibrillation without substantially cutting the fibers. The physical changes which occur during the passage of the pulp fibers through the space formed by the two working surfaces are reflected in the properties of the resulting treated pulp. Thus, the vigorous inter-fiber friction produced by mechanical treatment applied to the pulp produces a significant improvement in its most essential strength properties mentioned heretofore. The most unusual result derived from the process of this invention is a simultaneous improvement of burst, tensile, and tear strength in paper formed by the fiber, which has not been possible to achieve in the papermaking operations heretofore.

This can be seen by comparison of FIGS. 1 and 2. Both figures are reproductions of photographs of high-consistency pulp and low-consistency pulp of the same freeness (300 cc. CSF); and the photographs are 20 power enlarged taken over a ½ square inch field. The pulp of FIG. 1 was of a low-consistency of about 2½%, and was refined in a conventional jordan, while the pulp of FIG. 2 was refined at about 30% consistency in the manner described. For taking the photographs, both of the pulps were diluted to about 0.1% consistency. It will be readily apparent from FIG. 1 that the fibers have been very greatly fractured, while the high consistency fibers of FIG. 2 are substantially intact in length with substantially no fracturing.

The fuzzy areas in these photographs indicate the fibrillation which enhances fiber bonding in paper formation. Thus, it can be seen that at the same freeness, the substantially uninjured and unfractured and longer fibers obtained by high-consistency refining, result in improved bonding, greater strength, greater shrinkage with consequent increase in stretch, all making for the improved paper hereof.

One of the important features of the process of this invention is that the paper may be made from the high-consistency refined pulp, with a strength equal to paper made from low-consistency refined pulp, at a higher freeness level. Because of this higher freeness, faster drainage occurs in the papermaking machine, thus enabling higher speed papermaking machine operation. By the same token, at the same freeness, high consistency refined pulp forms paper of greater strength. Also, the power usage in connection with the present invention is generally lower for processing most pulps to a given strength development as compared to power usage for conventional papermaking low-consistency pulp beating or refining.

As mentioned hereinabove, the pulp mechanically treated in accordance with this invention may be diluted to a suitable low papermaking consistency and directed onto the paper machine. Also, if it is desired to further modify the physical properties of the high-consistency pulp in the manufacture of certain special grades of paper, some of the pulp or all could be subjected to conventional beating or jordaning operation after dilution to low-consistency, which, as is well known, may further increase burst and tensile strength, while reducing the tearing strength and freeness.

The following examples are given to define and to illustrate the present invention but in no way to limit it to proportions, conditions or equipment described therein. Obvious improvements will occur to any person skilled in the art. It will be noted that all tests on pulps produced were performed using the standard TAPPI methods, except that pulp handsheets were air-dried between blotters without being contacted with the conventional polished metal plates in order to more closely simulate drying conditions on a paper machine where some shrinkage of paper web occurs.

Example 1

Kraft pulp produced by the conventional kraft process using the mixture of Douglas fir and western hemlock chips and subsequently bleached to 80% G.E.R.S. (General Electric Recording Spectrophotometer) brightness was dewatered in a conventional screw press to a consistency of 30%. The pulp was metered into the center of the aforementioned double disc Bauer refiner 411 at the rate of 4000 lbs. of pulp per hour, while the plate clearance was initially adjusted to 0.030 inch. The relative tangential velocity (peripheral velocity) of the two rotating plates was 25,000 feet per minute and the compression exerted by the plates on the pulp was about 10 lbs. per square inch. The power usage resulting from a single pass of the pulp between the plate surfaces of the refiner was about 19 H.P. days/air dry ton of pulp. After a single pass through the refiner the pulp was discharged at the periphery thereof at about the same consistency and directed to a paper machine for conversion to paper.

The properties of the pulp and of the paper made from the pulp before and after the mechanical refining treatment described hereinabove are given in Table 1.

TABLE 1

	Untreated Defibered Pulp	Treated Refined Pulp
Freeness, cc. CSF (Canadian Standard Freeness)	710	500
Bursting Strength, percent (Mullin)	45	91
Tensile Strength, lbs./in. (Instron Tester)	4.3	14
Tearing Resistance, grams/lb. (Elmendorf Tear Tester)	3.9	5.1
Stretch, percent (Instron Tester)	3.8	8.8
Surface Strength (Tappi Wax Test—T-459)	6	18

The foregoing data clearly indicates the typical effects of the mechanical treatment on a pulp in accordance with the present invention. The increase of strength properties, and particularly increase of the tearing strength, along with the increase in other strength properties represents the general trend of modifications in paper properties derived by application of the process of this invention. These changes in properties are unique and different from those which are normally produced by the conventional beating or refining of pulps at low-consistency.

Example 2

Following the general procedure of Example 1, unbleached kraft pulp obtained by digesting a mixture of western hemlock and Douglas fir was fed at a consistency of 22% into a single disc refiner having an initial clearance between the two discs of 0.030 inch. The feed rate of the pulp was about 2000 lb./hour, the relative tangential velocity of the discs was about 10,300 feet per minute and the pressure exerted on the pulp was about 10 lbs./square inch.

After a single pass through the apparatus, the properties were as follows (the test instruments in Table 2 and following tables being the same as in Table 1):

TABLE 2

	Untreated Defibered Pulp	Treated Refined Pulp
Freeness, cc. CSF	740	670
Bursting Strength, percent	42	80
Tensile Strength, lbs./in	9.2	16.2
Tearing Resistance, grams/lb	3.9	5.1
Stretch, percent	3.1	8.4
Surface Strength (Wax Test)	2	12

Example 3

The procedure of Example 1 was substantially followed using western hemlock unbleached sulfite pulp at 30% consistency. The treating conditions were the same as in Example 1, except that the initial distance between the two rotating discs was 0.050 inch, the pulp feed rate was 8000 lbs./hour, and the power usage was 7 H.P. days/air dry ton of pulp.

The physical properties of the resulting pulp are shown in Table 3.

TABLE 3

	Untreated Defibered Pulp	Treated Refined Pulp
Freeness, cc. CSF	706	500
Bursting Strength, percent	47	75
Tensile Strength, lbs./in	14.4	18
Tearing Resistance, grams/lb	2	2.5
Stretch, percent	4.3	12.6
Surface Strength (Wax Test)	12	18

Example 4

The procedure described in Example 1 was repeated using fully cooked bagasse kraft pulp at 20% consistency. The parameters of the mechanical treatment were substantially the same as in Example 1, except that the power usage was 5 H.P. days/air dry ton of pulp.

The properties of the resulting pulp are shown in Table 4.

TABLE 4

	Untreated Defibered Pulp	Treated Refined Pulp
Freeness, cc. CSF	450	250
Bursting Strength, percent	30	50
Tensile Strength, lbs./in	6.4	10.6
Tearing Resistance, grams/lb	0.8	1.1
Stretch, percent	2	6
Surface Strength (Wax Test)	6	16

Example 5

The procedure of Example 1 was again repeated using western hemlock groundwood pulp at 20% consistency. The conditions of the mechanical treatment were substantially the same as in Example 1, except that the power usage was 43 H.P. days/air dry ton of pulp and the pulp feed rate was 1600 lbs./hour.

The properties of the resulting pulp are given in Table 5.

TABLE 5

	Untreated Defibered Pulp	Treated Refined Pulp
Freeness, cc. CSF	312	125
Bursting Strength, percent	19	32
Tensile Strength, lbs./in	5.8	10
Tearing Resistance, grams/lb	1	1.2
Stretch, percent	1	2
Surface Strength (Wax Test)	2	8

Example 6

Fully cooked cottonwood kraft pulp was processed in the manner described in Example 1, except that the power usage was 10 H.P. days/air dry ton of pulp and the pulp feed rate was 6600 lbs./hour.

The properties of the treated pulp are given in Table 6.

TABLE 6

	Untreated Defibered Pulp	Treated Refined Pulp
Freeness, cc. CSF	629	500
Bursting Strength, percent	39	57
Tensile Strength, lbs./in	10.2	12.6
Tearing Resistance, grams/lb	1.2	1.7
Stretch, percent	2.7	8.6
Surface Strength (Wax Test)	2	12

Example 7

This example illustrates the characteristic changes in strength properties of a pulp produced by the process of this invention, as compared to those produced by low-consistency beating procedure as exemplified by a conventional conical type refiner.

The pulp employed was defibered kraft pulp bleached to 65% G.E.R.S. brightness. Its initial freeness was 670 cc. CSF, and the freeness of the pulps after the mechanical treatment was 500 cc. CSF.

The properties of the pulps produced by the two different types of mechanical treatment are shown in Table 7.

TABLE 7

	Untreated Defibered Control Pulp	Present Invention Pulp at 30% Consistency	Conventional Beating (Jordan) Pulp at 3.5% Consistency
Bursting Strength, Percent	49	98	83
Tensile Strength, lbs./in	10	16	15
Tearing Resistance, grams/lb	4.1	5	3
Stretch, Percent	2.3	10	6.1
Toughness, ft. lb./square ft. (Instron)	3.3	15	8.5
Surface Strength (Wax Test)	8	18	14

From a review of the above data it is at once apparent that the process of this invention produces significant improvements in strength properties of the pulp which are not only different but also superior to those derived by the conventional low-consistency pulp beating procedure.

Example 8

This example illustrates the particular effect of the process of this invention on the tearing strength of the pulp as compared to the results obtained with low-consistency conventional refining.

The following Table 8 indicates tearing strength values obtained on processing semi-bleached kraft pulp of 65% G.E.R.S. brightness to various freeness levels.

TABLE 8

	Tearing Resistance, grams/lb.			
	Conventional Beating (Jordan) 3.5% Consistency	Pulp Treatment at High-Consistency		
		10%	18%	30%
Pulp Freeness, cc. CSF:				
653 (Untreated Defibered Pulp)	3.6	3.6	3.6	3.6
600 (Refined Pulp)	3.5	3.9	4.2	4.6
500 (Refined Pulp)	3.3	3.95	4.3	4.8
400 (Refined Pulp)	2.9	4.0	4.4	5.1

The foregoing data clearly indicates that the trend in the tearing strength development using the present invention is directly opposite to that when conventional low-consistency pulp beating is applied.

MANUFACTURE OF PAPER

With reference to paper manufacture, in the heretofore conventional papermaking process, cellulosic pulp is deposited from suspension in water on a traveling wire to produce an inter-felted paper web which subsequently is dried during its passage through the drying section of the paper machine and finally wound up on a reel.

Papers made from a pulp beaten at a low consistency are usually characterized by having higher tensile but lower tear and much lower stretch in the machine direction than in the cross machine direction of the paper. The unequal strength properties of such conventionally produced papers and especially their inherent low stretch and toughness seriously impair their utility for many commercial uses.

It is also known that the with-machine direction stretch may be improved by a conventional blade-creping operation during which a paper web which adheres to a rotating cylinder is removed therefrom by a doctor blade. This blade creping procedure, however, does not improve the cross-machine direction stretch of the finished creped paper product.

In order to increase the stretch of paper in the cross-machine direction, processes have been developed wherein a diagonal set of creping wrinkles is produced by causing the doctor blade to move in a diagonal direction during the creping operation thereby producing a paper having crossing sets of creping wrinkles disposed diagonally of the axis of the paper web. Although the stretch of the resulting creped paper is improved in the cross-machine direction, such paper is characterized by relatively low strength properties, particularly tensile strength, which renders it unsuitable for many uses requiring papers of high overall strength.

In another process of making extensible uncreped paper, a moist paper web is passed between a heated metallic roll and a rubber belt, whereby the paper web is compacted in the machine direction without being creped on its surface. The resulting paper has improved strentgh in the with-machine direction; however, little or no change is effected in its cross-machine direction. In an attempt to produce paper which would be extensible equally in both directions, the latter method has been modified by compacting the paper web on a bias, first in one direction, then in the other.

This is accomplished by passing a moist paper web through aforementioned compaction units including a roll and a rubber belt, disposed at appropriate angles to the direction of the web. The resulting compacted flat paper, although characterized by isotropic stretch, has other strength properties, particularly tensile and tear, substantially unchanged as compared to untreated flat paper. Furthermore, the process is complex and involves the use of expensive equipment utilizing a great deal of space.

An additional embodiment of the present invention includes the provision of high strength paper made from the high-consistency refined pulp hereof, which is characterized by substantially isotropic stretch. This may be accomplished by following the process of this invention until a moist paper web is formed, passing such moist paper web through a nip formed by a hard roll and a soft elastic roll, the rolls being positioned in the drying section of the paper machine, the hard roll being driven at a greater speed than the elastic roll, and thereafter drying the paper web in the remaining portion of the drying section of the paper machine. As a result of this treatment, the paper which is compressively creped at an angle of about 90° with respect to the direction of the web travel, has stretch substantially equal in all directions as well as markedly improved overall strength characteristics.

Another feature of the invention, and that which produces a paper characterized by substantially isotropic toughness, is the drying of the paper web in the drying section of the paper machine under reduced tension, as compared to the usual tension applied to the paper web on the paper machine during its drying. In addition to having toughness substantially equal in all directions, the resulting paper also is characterized by increased overall strength properties.

The two additional features of this invention described hereinabove may also be applied in one papermaking operation by first passing the moist web through a nip formed by a hard roll and an elastic roll and thereafter drying the resulting creped web under reduced tension. The paper produced in this manner has overall strength properties still further improved and is characterized by a substantially isotropic stretch.

In the preparation of the high strength paper of the invention having a substantially isotropic stretch, the moist paper web **51** (FIG. 7) between drying sections in the papermaking machine comprising sets of drying rolls **52** and **53**, is compressively creped during its passage between a hard roll **54** and a soft elastic rubber roll **56** having a Shore durometer hardness of 10° to 45°, wherein the hard roll mounted on shaft **57**, is driven at the speed greater than the elastic roll mounted on shaft **58**, preferably by at least 8%. The process of making compressively creped, extensible paper which may be applied in the present invention and the products derived therefrom are described in U.S. Patent No. 3,104,197, dated Sept. 17, 1963, for "Extensible Paper and the Process of Producing the Same." However, the process conditions and the properties of the finished paper product of the present invention are to be distinguished from those described and claimed in that patent inasmuch as the significant advantage of compressively creping a paper web in the process of this invention is that a paper product characterized by isotropic stretch and unusually high other strength properties can be produced.

As stated hereinabove, high strength paper can also be produced in accordance with the invention in such a manner as to impart thereto substantially isotropic toughness characteristics. This may be accomplished by drying the moist paper web in the end portion of the drying section of the paper machine under reduced tension. In the normal papermaking operation, the moisture content of a paper web at the end portion of the drying section of the paper machine varies from about 40% to about 5%. The moist paper web passes around the drying rolls under tension caused by substantially constant speed of the dryers and by dryer felts which carry the moist web and presses it against the surface of the dryers. This restrains the paper web from shrinking, introduces stresses to the drying web and gives a finished dried paper characterized by a relatively low extensibility and highly directional strength properties.

The tension on a paper web during drying may be reduced by applying a negative draw between the drying sections of the paper machine, that is, for example, by driving the last section of the paper machine dryers at a somewhat lower speed than the preceding section. A reduced tension may also be produced by slacking the tension of the dryer felts in the end portion of the drying section of the paper machine thereby increasing shrinkage of the web in the cross machine direction and equalizing toughness in both directions. These overall physical properties of the web may further be enhanced by removing the dryer felt in the end portion of the drying section of the paper machine thus allowing more contraction of the web thereby further increasing its overall strength properties with the exception of tensile strength which will be substantially unimpaired or slightly reduced.

Another significant property of the high strength paper produced in accordance with this invention is its high porosity. This property is primarily due to the use of the high-consistency mechanically treated pulp which gives during its conversion into paper a more porous, or less dense sheet than could be produced on a paper machine from the same pulp produced by conventional low consistency refining methods. Thus, the paper product of this invention differs from other known paper products by possessing, in combination, unusually high overall strength, extensibility, and porosity.

The following examples are given to define and to illustrate the present high strength paper invention but in no way limit it to conditions or equipment described therein. Obvious modifications will occur to any person skilled in the art.

Example 9

This example illustrates a typical procedure for the manufacture of the herein described high strength paper.

Unbleached kraft pulp derived from a mixture of Douglas fir and western hemlock was passed at 29.4% consistency through the aforementioned double disc Bauer 411 refiner having the plate clearance adjusted to 0.03 inch. The relative tangential velocity of the rotating plates was 25,000 feet per minute, the compression exerted by the plates on the pulp was 10 lbs. per square inch, and the power usage resulting from a single pass of the pulp between the plates was about 27 H.P. days/air-dry ton of pulp. The treated pulp had a freeness of about 500 cc. C.S.F. (Canadian Standard Freeness). It was discharged at substantially the same consistency and diluted with sufficient water to form a pulp slurry having a consistency of 0.5%. This slurry was run onto a conventional Fourdrinier paper machine and made into paper. For comparison, the same pulp was beaten and refined at 2.5% consistency in a conventional refining equipment to a freeness level of about 500 CSF and made into paper in the same manner. The properties of the conventionally refined control paper and those of paper produced in accordance with this invention are given in Table 9.

TABLE 9

	Control Paper	Present Invention Paper
Stretch, Percent:		
WMD [1]	2.9	3.3
CMD [2]	5.1	6.2
Toughness, ft.-lbs./ft. [2]:		
WMD	7.0	8.4
CMD	6.5	6.7
Tear, gms./lb.:		
WMD	2.0	4.7
CMD	2.6	6.1
Tensile Strength, lbs./inch:		
WMD	30.8	29.6
CMD	14.1	11.4
Gurley Porosity, sec./100 cc	22	7.8

[1] With machine direction.
[2] Cross machine direction.

The foregoing data clearly indicate a significant increase in overall strength properties of the paper produced in accordance with this invention, as compared to the conventional control paper. The increase of stretch, toughness and tear characteristics as shown for the paper of the present invention, accompanied by a higher porosity and slightly decreased tensile values represents the general trend of modifications in paper properties which may be attained by application of the process of this invention. These improvements in paper properties are unique and significantly higher than those that are normally obtainable using pulps refined at conventional low consistency.

Example 10

This example illustrates the manufacture of high strength paper characterized by isotropic stretch.

The procedure of Example 9 was generally followed, except that bleached kraft pulp was employed and the power usage was 18 H.P. days/air-dry ton of pulp. After the paper web was formed and partially dewatered to a moisture content of about 35% based on the oven-dry weight of the paper web, it was passed through a nip formed by a hard metallic roll and a rubber covered roll, the Shore durometer hardness of the rubber being 35°, and the surface speed of the rubber roll being 14% lower than that of the hard roll. The resulting compacted and creped paper then was dried in the remaining section of the paper machine. For comparison, two control papers also were produced from the same pulp but refined at 2.5% consistency. One control paper was made without compressive creping, while the other was compressively creped under the same conditions as the paper of the present invention.

The results are given in Table 10.

TABLE 10

	Control Paper		Present Invention Paper, Compressively Creped
	Flat	Compressively Creped	
Stretch, percent:			
WMD	2.0	6.2	8.9
CMD	3.6	5.0	8.9
Toughness, ft.-lbs./ft.²:			
WMD	9.2	16.3	28.1
CMD	10.4	7.5	17.4
Tear, gms./lb.:			
WMD	2.6	2.7	3.1
CMD	3.0	3.3	4.2
Tensile Strength, lbs./inch:			
WMD	59.8	35.4	43.9
CMD	32.6	20.2	24.8

It is clearly evident from the above data that the paper of the present invention is characterized by isotropic stretch as well as by toughness and tear properties markedly superior to those of the two control papers. It is also evident that the tensile values of the present invention paper are substantially higher than those of the compressive creped control paper.

Example 11

This example illustrates the preparation of the paper having isotropic toughness. The procedure of Example 9 again was generally followed except that the power input was 18 H.P. days/air-dry ton of pulp. The partially dried paper web was passed through the end portion of the drying section of the paper machine under reduced tension by removing one dryer felt so that a substantial contraction of the web was allowed. For comparison, a control paper was produced from the same pulp as employed in the present example but under tensions conventionally applied to the paper web in the drying section of the paper machine.

The results are presented in Table 11.

TABLE 11

	Control Paper	Present Invention Paper
Stretch, Percent:		
WMD	2.0	3.9
CMD	3.6	6.6
Toughness, ft.-lbs./ft.²:		
WMD	9.2	16.1
CMD	10.4	16.7
Tear, gms./lb.:		
WMD	2.6	4.4
CMD	3.0	5.3
Tensile Strength, lbs./inch:		
WMD	59.8	53.8
CMD	32.6	27.3
Gurley Porosity, sec./100 cc.	20.0	13.2

It is readily apparent that the paper of this invention is not only characterized by isotropic toughness but also by markedly increased strength properties and higher porosity, as compared to the control paper.

Example 12

This example illustrates the manufacture of paper characterized by isotropic stretch and superior overall strength properties.

This paper was produced by following generally the procedure of Example 10 with application of reduced tension in the drying section of the paper machine as set forth in Example 11. For comparison, the same papermaking procedure was applied in the manufacture of control paper formed from the same pulp conventionally refined at 2.5% consistency.

The results are given in Table 12.

TABLE 12

	Control Paper	Present Invention Paper
Stretch, Percent:		
WMD	9.1	13.5
CMD	5.5	10.6
Toughness, ft.-lbs./ft.2:		
WMD	20.1	39.8
CMD	8.9	19.3
Tear, gms./lb.:		
WMD	3.3	4.8
CMD	4.2	6.2
Tensile Strength, lbs./inch:		
WMD	31.5	37.3
CMD	21.3	22.3

From a review of the above data it is at once apparent that the process of this invention including compressive creping of the moist paper web followed by its drying under reduced tension produced significant increases in overall strength properties of the paper as compared to those of a paper produced from the same pulp refined under the conventional low-consistency conditions.

Thus, it will be apparent that by the present invention we have provided a process for the manufacture of high strength papers which possess remarkably high overall strength and which may be manufactured in such a manner as to possess isotropic stretch or toughness. These paper products may be employed to advantage in many end uses, including wrapping, thus providing better protection to the contents due to superior energy absorption capacity and resistance to tearing of the paper. The high stretch of the paper enables it to absorb shocks without immediately breaking, a feature which is of great importance in packaging. Newsprint and other printing papers can be made using smaller amounts of expensive chemical pulps without impairing the products' overall quality. Furthermore, household towels, napkins and tissues made according to this invention benefit from greater resiliency and compressibility of the paper. The porous structure of the paper due to its high porosity renders it useful in impregnation or saturation with various resinous compositions.

What is claimed is:

1. A continuous process for effecting fibrillation of substantially defibered separated cellulosic fibers along the surfaces thereof while substantially maintaining the length of said fibers, which comprises providing a fiber pulp which is of a high consistency of at least about 10% and in the form of a semi-solid, non-flowable and non-pumpable lumpy mass with the fibers in intimate contact; providing a fiber fibrillating, working space comprising a pair of opposed working surfaces coaxially disposed in generally facing relation throughout substantially the entire extent of said working space and in relative rotational motion with respect to each other about a common axis defining such coaxial disposition and having an inlet for said pulp and an outlet therefor; continuously feeding said pulp while in such lumpy, semi-solid condition in a single pass through said inlet and continuously into and through said working space in a direction away from said inlet to said outlet and at a rate to maintain said working space substantially packed with a continuous movement of said fibers under compression and in intimate contact to provide a continuous pad of said pulp between said working surfaces while maintaining said fibers in intimate contact in said pad to cause such fiber fibrillation along the fiber surfaces by inter-fiber friction in said pad and without substantial fracturing of said fibers, while said pulp is thus fed and continuously worked on in said working space applying pressure to the continuous pad by means of said working surfaces and at the same time maintaining said working surfaces spaced apart a distance obviating substantial fracturing of said fibers, and continuously effecting discharge of fibrillated fibers from said outlet simultaneously with said continuous feeding of said pulp through said inlet.

2. The process of claim 1 wherein the fiber pulp fed into said working space is at least partially chemically defibered, and the pressure applied to the pulp is between about 5 to 20 pounds per square inch.

3. A continuous process for effecting fibrillation of substantially defibered separated cellulosic fibers along the surfaces thereof while substantially maintaining the length of said fibers, which comprises providing a fiber pulp which is of a high consistency of above 20% and in the form of a semi-solid, non-flowable and non-pumpable lumpy mass with the fibers in intimate contact; providing a fiber fibrillating, working space comprising a pair of opposed disc-shaped working surfaces coaxially disposed about a common fixed axis in generally facing relation throughout substantially the entire extent of said working space and having an inlet for said pulp and an outlet therefor; effecting relative rotation between said surfaces about said common fixed axis; continuously feeding said pulp while in such lumpy, semi-solid condition in a single pass through said inlet and continuously into and through said working space in a single path in a direction away from said inlet to said outlet and at a rate to maintain said working space substantially packed with a continuous movement of said fibers under compression and in intimate contact to provide a continuous pad of said pulp between said working surfaces while maintaining said fibers in intimate contact in said pad to cause such fiber fibrillation along the fiber surfaces by inter-fiber friction in said pad and without substantial fracturing of said fibers, while said pulp is thus fed and continuously worked on in said working space applying pressure to the continuous pad by means of said working surfaces and at the same time maintaining said working surfaces spaced apart a distance obviating substantial fracturing of said fibers, and continuously effecting discharge of fibrillated fibers from said outlet simultaneously with said continuous feeding of said pulp through said inlet, said opposed surfaces being roughened to enhance imparting frictional energy to the fibers.

4. A continuous process for effecting fibrillation of substantially chemically defibered separated cellulosic fibers along the surfaces thereof while substantially maintaining the length of said fibers, which comprises providing a fiber pulp which is of a high consistency of at least about 10% and in the form of a semi-solid, non-flowable and non-pumpable lumpy mass with the fibers in intimate contact; providing a fiber fibrillating, working space comprising a pair of opposed disc-shaped working surfaces disposed in facing relation throughout substantially the entire extent thereof and in relative rotational motion with respect to each other about a common axis at a relative tangential velocity of at least about 1000 feet per minute and having an inlet for said pulp adjacent said axis and an outlet therefor spaced radially outwardly from said inlet; continuously feeding said pulp while in such lumpy, semi-solid condition in a single pass through said inlet and continuously into and through said working space in a single path in a direction away from said inlet to said outlet and at a rate to maintain said working space substantially packed with a continuous movement of said fibers under compression of about 5 to 20 pounds per square inch and in intimate contact to provide a continuous pad of said pulp between said working surfaces while maintaining said fibers in intimate contact in said pad to cause such fiber fibrillation along the fiber surfaces by inter-fiber friction in said pad and without substantial fracturing of said fibers, while said pulp is thus fed and continuously worked on in said working space applying pressure to the continuous pad by means of said working surfaces and at the same time maintaining said working surfaces spaced apart a distance obviating substantial fracturing of said fibers, and continuously effecting discharge of fibrillated fibers from said outlet simultaneously with said continuous feeding of said pulp through said inlet.

5. A continuous process for effecting fibrillation of substantially defibered separated cellulosic fibers along the surfaces thereof while substantially maintaining the length of said fibers, which comprises providing a fiber pulp which is of a high consistency of at least about 10% and in the form of a semi-solid, non-flowable and non-pumpable lumpy mass with the fibers in intimate contact; providing a fiber fibrillating, working space comprising a pair of opposed disc-shaped working surfaces disposed in face to face relationship and in relative rotation with respect to each other about a common axis, one of said surfaces having an inlet into said working space adjacent said axis, said working space having an outlet therefor adjacent the periphery of said surfaces; continuously feeding said pulp while in such lumpy, semi-solid condition in a single pass through said inlet and into and through said working space and at a rate to maintain said working space substantially packed with said fibers under compression and in intimate contact to provide a continuous pad of said pulp between said working surfaces while maintaining said fibers in intimate contact in said pad to cause such fiber fibrillation along the fiber surfaces by inter-fiber friction in said pad and without substantial fracturing of said fibers, and while said pulp is thus fed and continuously worked on in said working space applying pressure to the continuous pad by means of said working surfaces and at the same time maintaining said working surfaces spaced apart a distance obviating substantial fracturing of said fibers and also maintaining said surfaces axially spaced apart a distance rendering said working space unobstructed along a radial plane therethrough, said opposed surfaces being roughened to enhance imparting frictional energy to the fibers.

6. The process of claim 4 in which the pulp consistency is between 20 to 35%.

7. The process of claim 5 in which the pulp is chemical pulp, the pulp consistency is between 20 to 35%, and the pressure applied to the pulp by means of said working surfaces is about 5 to 20 pounds per square inch.

8. The process of claim 6 in which the pulp consistency is about 30%.

9. A refined papermaking cellulosic pulp obtained by the fiber fibrillation process of claim 1 wherein such substantially unfractured fibrillated fibers are substantially intact in length compared to that of the same pulp prior to fibrillation thereof and have fibrillated surfaces of fine, free, hair-like strands projecting from said surfaces; the tear strength of paper made from said fibrillated pulp being greater than that of paper made from the same pulp prior to said fibrillation as a result of said substantially intact fiber lengths, and said paper also having increased burst, tensile and stretch strengths compared to paper made from said pulp prior to said fibrillation.

10. The papermaking pulp of claim 9 in which the pulp is chemical wood pulp.

11. A paper web containing the papermaking pulp of claim 9.

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S. LEON BASHORE, *Primary Examiner.*