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Hydrostatic compression forming for wood and novel ligneous material therefrom

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ABSTRACT

A novel forming method of wood is disclosed. In the method, a primary wood of which water content was adjusted in the range of 10-80wt% is brought into softened state, then said softened wood is compressed for forming with hydrostatic pressure by means of liquid as pressurizing medium, and then said compressed wood is treated with a fixation means of compressed state selected from either a step wherein a shaping jig or a mold is used, or heating in a particular temperature range is conducted for constraining volume relaxation of compressed wood, or cooling down below the softening point of said wood is conducted, or compact-packing together with hard particles into a vessel followed by heating is conducted, or a primary wood is chemically treated to form a localized wood-plastics composite before applying hydrostatic compression. Also, unique ligneous material obtained by the above-mentioned method or lumber sawn out from said material is offered.

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COMPLETE SPECIFICATION

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Hydrostatic compression forming for wood and novel ligneous material therefrom

The following statement is a full description of this invention, including the best method of performing it known to me/us:-

B. Background of the Invention

1. Field of the Invention

This invention relates to a novel method of processing wood to obtain a unique ligneous material having high hardness, beautiful grain and excellent external appearance. More specifically, this invention relates to a compression forming method for shaping a wood by using hydrostStic force of pressurizing liquid.

This invention can be applied to a manufacturing process to produce economically, for example, a shaped ligneous material with improved surface hardness, or a sawn lumber with beautiful grain as well as improved physical properties, or a so-called fancy log with decorative and complicated external appearance, without using a mold. The application of this invention is, however, not necessarily limited to these, also this invention is useful in other ways of application in industry.

2. Description of the Prior Art

A forming method, so-called densification for soft wood such as cedar, to improve its physical properties as well as its shape has been known since long ago. In the densification, a primary wood is heated in order to bring it into softened state, then compressed by using a mold for forming it into a desired shape to obtain a shaped ligneous material with high surface hardness. The word "primary wood" means a log, lumber, or any other form of wood used as raw material which is to be treated in the process of this invention.

For example, a method has been practised commercially, in which a timber of cedar is heated by hot water or saturated steam at around 100 ℃ to be brought into plasticized state, then it is compressed with solid surfaces of a mold to form a pillar having polygonal cross section, then its shape is stabilized by cooling or drying it during kept hold for many hours in the mold.

Also, another method has been known, in which a primary wood is plasticized by means of steam with high temperature and pressure, then it is loaded between a pair of mold plates in the steam under high or atmospheric pressure to be compressed, then its shape is stabilized by leaving it while being held in the mold in the atmosphere of high temperature steam for some hours.

In either case, a shaped ligneous material having a higher density and a higher hardness in comparison with a primary wood can be obtained. It should be noted that compression of wood by mold surfaces, when carried out to excess, can cause dammage to the wood tissues resulting in local deterioration of hardness. Historically, however, compression of wood has been conducted almost exclusively by the use of solid surfaces of mold.

Moreover, as described above, it is absolutely necessary for a compressed ligneous material to be kept hold in a mold closed under mechanical force for many hours, in order to stabilize the shape as it is of compressed ligneous material.

Up to this time, a few methods have been practiced commercially with the above purpose in view. For example, cooling water is supplied through an inner path of the mold to cool down the temperature of commpressed wood below the softening point by spending substantial time. Then, the shaped material is taken out of a mold. In another way, after compressing a softened wood, the mold holding the compressed wood is treated in steam at around 180℃ for some time, then the shaped material is cooled and taken out of a mold.

Without said trearment by high temperature steam, the stress generated by the forming is retained in a compressed wood and will cause relaxation of compressed state of the wood when the shaped ligneous material is heated to high temperature beyond its softening point. That means, the volume of a compressed wood is recovered up to nearly original volume, (i.e. this is so-called volume relaxation), and also a rebound in its shape takes place until it approaches to original shape.

It is evident from the above discussion that a long residence time in the mold is required for wood in the conventional densification method, which will inevitably push up the production cost of shaped articles since manufacturing cost of a mold is generally rather high.

For the purpose of reducing a residence time in a mold, a method was proposed in an earlier development. That is the use of a jig with sufficient strength to withstand a volume relaxation (called a shaping jig hereinafter). The jig is usually installed inside the mold, and softened wood is compressed inside the jig. When compression is over, the jig parts are firmly connected together mechanically along their edge lines, and the jig holding the compressed wood inside is immediately removed from the mold.

This method may be useful for manufacturing smaller shaped articles. But it can not be practical for production of large material such as lumber for building a frame house, since rather thick, heavy metal walls are need for the construction of the jig.

In practice, after all, there have been almost no method, except use of molds or jigs, useful for the compression of wood and for the fixation of the resulting compressed structure or state. At the same time, no method has been proposed so far to utilize hydrostatic pressure for direct compression of plasticized wood in a liquid.

C. Summary of the Invention

The object of the present invention is to provide a method for obtaining a shaped ligneous material with improved hardness, density, without utilizing a mold.

A further object of this invention is to provide a method for fixing the compressed state or internal compressed structure of densified wood obtained by aforementioned forming to prevent it from volume relaxation or dimensional change during its use.

A still further object is to provide a shaped ligneous material produced by employing above method having a decorative external appearance and a beautiful internal grains which become visible when sawn. Other objects and advantages of the present invention will become apparent from the detailed description to follow taken in conjunction with the appended claims.

According to a first aspect of the invention, a primary wood such as a log, sawn lumber and the like is brought into softened state by heating it above its softening temperature by means of, for example, hot water or steam at high temperature. Then, the softend wood is compressed up to a desired compression ratio, for example, roughly 50% by cross-sectional ratio to shape a densified wood by means of hydrostatic pressure of a pressurizing liquid in replacement of a mold used in conventional technologies. By an effect of the hydrostatic compression, the physical properties such as density and surface hardness of a primary wood in the form of log, column, plank, square lumber and the like increase with the decrease of its volume, and a densified ligneous material with improved physical properties is obtained.

Features of the hydrostatic method in this invention will be explained as follows, taking a log as an example of a primary wood. At the moment when the pressure of pressurizing liquid exceeds the yielding stress of softend log, compression by hydrostatic pressure starts. Generally, the compression is considered to begin at the surface layer part of a log(i.e. sap wood) which is softer than the heart wood. At the first stage of compression where the sap wood is compressed, a log is compressed by isostatic force exerted by pressurizing liquid in the direction perpendicular to annual rings. Consequently, the diameter of the log decreases due to collapse of cells in early-growing part (i.e. early wood). But, late-growing part of a log (i.e. late wood) which cells are stronger in mechanical strength due to small cell size and thick cell walls, tends to resist deformation by compression.

Therefore, the length in the tangential direction of each tree ring (i.e. the contour length), is hardly changed by compression. As the result, individual annual rings display wave like pattern at the surface layer part, and a complicated undulation, reflecting the internal deformation, appears on the side surface of the compressed log. At the stage of this surface layer compression, a log having a decorative appearance, a so-called a fancy log type, is obtained as the shaped ligneous material.

At the later stage of compression, the surface layer part, which has already been mechanically strengthend by preceding compression, is forced to cave in towards the softened heart wood. In consequence, the cross section shows the highly deformed annual rings consisting of non-circular closed curves with many large bends. The highly compressed log is in itself useful due to its decorative appearance. But it is also a useful starting material for production of boards, pillars and other sawn material with beautiful grains.

On releasing the pressure of pressurizing liquid at the same temperature used during hydrostatic compression, a volume relaxation of compressed log takes place immediately, and the log recovers the volume by a recovery ratio of about 90%. However, a densified wood obtained according to the compression forming of the present invention has tendencies to allow a lower incidence of cracking by drying and to reduce the size of cracking, though a substantial expansion by volume relaxation is inevitable.

That is to say, one of the advantages of this invention is that a densified ligneous material in the form of logs obtained as above-mentioned does not need a processing named karfing for aging, though a timber usually needs karfing to prevent it from craking by drying before it is normally used without compression.

To bring a primary wood into softened state, it is necessary to heat it above the softening temperature of lignin and hemicellulose. The softening point of a primary wood is dependent on the water content of wood, and it is generally around 100℃ if a wood contains moisture above its fiber saturation point. The softening temperature rises with the decrease in moisture content below its fiber saturation point. The moisture content quoted above means the percentage by weight of total water existing in the ligneous tissue versus total weight of the wood. Total water comprises free water existing freely in the cell cavity and combined water bonded to components of ligneous material by hydrogen bond and so forth.

Hydrostatic compression becomes substantially difficult if free water content is exceedingly high, as the space in vascular tissue and cells is then almost filled with free water. Hydrostatic compression is also difficult if water content is so low as to make a primary wood extremely dry. Many cracks develop on the surface of wood wherefrom pressurizing liquid breaks in. Further, the aforementioned rise of softening point of wood along with drying causes inconvenience for softening the wood. For these reasons, watercontent of a primary wood is desirable to be from 10% at lowest and 80% at most.

Furthermore, in the method aforementioned, softening a primary wood and compressing the softend wood by hydrostatic pressure can be done simultaneously by using, for example, hot water at higher temperature preferably above the softening point of the primary wood.

According to a second aspect of the invention, a shaped ligneous material stabilized against the temperature in various uses through restraining the volume relaxation is obtained by treating the densified wood with fixation means to fix the compressed state of wood.

Fixation of compression state is defined as a semi-permanent retention of the compressed state in terms of volume, dimension, shape, and internal structure units like tracheas, pits or cell cavities and so forth in the compressed and temporarily stabilized ligneous material, irrespective of change in humidity and ambient temperature imposed on a shaped ligneous material.

Conventionally, fixation of compressed state has been achieved by heating densified wood in the mold for hours, in case of a compression shaping by recourse to a mold, so far. While, a combination of an upper concept regarding the fixation of compressed state and the hydrostatic processing has not been known in case of a hydrostatic compression processing of wood, as the method itself is quite novel.

According to a third aspect of the invention, a shaped ligneous material fixed in the compression state in desired shape is obtained by loading a densified wood so produced as aforesaid hydrostatic compression in a shaping jig under the compressed condition, then leading the densified wood into relaxing slightly in its volume by reducing liquid pressure, so that the densified wood presses its surface against the inside wall of the jig. The shape of the densified wood will be defined by the shape of the jig cavity.

By this method, such shaped article as a column with excellent surface hardness and high accuracy in circular cross section, or a pillar with desired geometrical pattern on its surface, for example, can be available.

This method has no recourse to any mold but makes use of only a shaping jig fabricated at low cost, resulting in economizing fabrication cost of a mold and its associated apparutus as well as running cost. Further, loading the compressed wood in the jig is much easier than loading a log in a mold in the air, as it is carried out in the pressurizing liquid. Consequently, manpower can be cut down as well.

According to a fourth aspect of the invention, a shaped ligneous material fixed in the compression state is obtained by compressing a softened wood using aforesaid hydrostatic pressure of a pressurizing liquid, then cooling down the densified wood by lowering the liquid temperature while holding the liquid pressure. In the method of the fourth aspect of the invention, the cooling temperature is desirable to be chosen between ambient temperature and softening point of a primary wood.

As a way of cooling, a pressurizing liquid of low temperature can be charged into the vessel being used for hydrostatic compression under high pressure while discharging hot liquid to exchange the hot liquid for cold liquid in a short time.

According to the method of the fourth aspect of the invention, a compressed state of densified wood shaped by hydrostatic compression is fixed without using any shaping jig. The shaped ligneous material obtained by this method has a decorative appearance on the whole surface, displaying furrows which is characteristic of hydrostatic compression, originating from selective compression of softer parts of the primary wood.

According to a fifth aspect of the invention, a shaped ligneous material fixed in the compression state is obtained by compressing a softened wood using aforesaid hydrostatic pressure of a pressurizing liquid, then heating up the densified wood by elevating the liquid temperature while holding the liquid pressure.

Upon heating the densified wood while keeping the liquid pressure as described above, a compressed state is presumably fixed by the effect of hydrolysis of hemicellulose and lignin contained in ligneous tissue, resulting in elimination of internal stress generated in a ligneous material durig compression.

The heating temperature is desirable to be in the range of 140-180℃ where the abovementioned change takes place. The shaped ligneous material obtained by this method also has a decorative appearance on the whole surface, displaying characteristic furrows which are attributable to hydrostatic compression.

The advantage of the fifth aspect of the invention is that the effect of fixation of a compressed state by heating of a densified wood sustains permanently, on the contrary to the fact that the effect of fixation by cooling of a densified wood lasts more or less temporarily.

According to a sixth aspect of the invention, a shaped ligneous material fixed in the compression state is obtained by compressing a softened wood using aforesaid hydrostatic pressure of a pressurizing liquid and by stabilizing the compressed state temporarily, then releasing said liquid pressure. The temporarily stabilized densified wood is then loaded in a treatment vessel and the space between the surface of densified wood and the inner wall of the vessel is filled up with heat-resistant hard particles in the state of compact-packing which is nearly in the state of so-called closest packing. The whole contents in the vessel is then heated to fix the compressed state of the wood.

In the method of the sixth aspect of the invention, hard particle having the particle size in the range of 0.3-4.0 mm can be used. Small particle size is desirable for fixation of compressed state of a densified wood having fine undulations on its surface with decorative appearance or for a fixation of a densified planks formed by compression between heated mold plates for which smooth surface is demanded. Particle size less than 0.3 mm is not desirable, as it is difficult to remove particle from the decorative surface of shaped ligneous material after completing fixation.

On the other hand, the particle size in the range of 2-3 mm is convenient in case of forming a densified log for sawing to produce sawn lumber after the densification. The particle size beyond 4 mm is not desirable, as a surface of ligneous shaped article becomes rough and pneumatic conveyance of particles to and from the vessel becomes difficult.

In the method of sixth aspect of the invention, filling up the space with particles is necessary to the extent of minimum occupation of the vacancy in the vessel or filling to the state of compact-packing by means of, for example, vibration of the vessel. At the state of compact-packing as described above, volume relaxation of the densified wood, which is fixed temporarily, is restrained; the force to expand in radial direction of wood is checked by the effect of frictional force exerted among hard particles.

By heating the whole contents in the vessel under the restrained condition on relaxation, the compressed state of densified wood is permanently fixed. The heating temperature in the range of 180-250 ℃ is used in case of dry-heating, and 140- 190℃ in case of wet-heating, respectively. Saturated steam, for example, can be used, resulting in the completion of fixation in short time due to very good heat transfer attributable to the heat of condensation of steam, as the heating fluid can pass through the layer of hard particles. Superheated steam also can be used, resulting in simultaneous progress of fixing of compresed state and drying of the shaped ligmeous matrrial.

Futher more, the fixation method by this invention described above can be also applied to a densified wood formed by utilizing a mold for compression. In this case, however, the mold is used for shaping a softend wood into a densified wood with desired cross-sectional shape only for short time. The fixation of compressed state which needs many hours after compression shaping is achieved by loading the densified wood together with heat-resistant hard particle in the vessel used in the sixth aspect of the invention. Productivity per mold for a shaped ligneousmaterial is fairly improved, as the residence time of a densified wood in the mold is remarkably shortend by this invention.

Still further, according to a seventh aspect of the invention, residual stress in a primary wood in the form of log, lumber and the like is eliminated by loading a primary wood together with heat-resistant hard particle in a vessel, then filling up all the space in vessel with the particle to become the state of compact-packing as aforementioned, then heating the whole contents in the vessel.

By the method of the seventh aspect of the invention, logs and lumber free from dimensional changes irrespective of changes in moisture and ambient temperature is produced conveniently with high productivity.

Lastly, an invention utilizing a chemical means on a primary wood to make hydrostatic compression and succeeding fixation easy is described below.

According to an eighth aspect of the invention, a shaped ligneous material fixed in the compression state is obtained by treating a dried primary wood with resin impregnation using an impregnation liquid containing vinyl monomer as a principal ingredient, then producing a ligneous material containing synthetic resin in the wood by polymerizing the monomer, then compressing the ligneous material by applying hydrostatic compression at the temperature above the softening point of primary wood, then cooling the compressed ligneous material while holding the liquid pressure.

In the method by abovementioned invention, the liquid containing vinyl monomer penetrates into the vacancy existing in the primary wood. It also fills cracks on the side and end surfaces, and finally polimerizes into synthetic resin. As the synthetic resin exists in the manner of plugging aforesaid cracks and vacancy, it can hinder the pressurizing liquid to penetrate into the wood at the time of hydrostatic compression. This is important, as hydrostatic compression becomes substantially difficult if pressurizing liquid penetrate into the primary wood through cracks on its surfaces.

In the method of the eighth aspect of the invention, a monomer to be used is of the liquid type having affinity for a primary wood. A single substance or mixtures chosen from styrene, methyl methacrylate, vinyl acetate, hydrophilic acrylic monomers such as polyethylene glycol methacrylate, and glycidyl acrylate, unsaturated polyesters, and so forth can be used in the present invention, though the invention is not limited to these example cited above.

Further, in the method of the eighth aspect of the invention, the impregnation liquid can contain, as one of the principal ingredient, at least one kind of high or medium molecular weight compound with high or medium degree of polymerization selected from high polymers, pre-polymers or origomers, along with aforesaid monomer. These polymers need to be soluble in the vinyl monomer and are the component to regulate the viscosity of impregnation liquid. By using the impregnation liquid containing the polymer dissolved in vinyl monomer, the penetration of the pressurizing liquid into a primary wood can prevented more effectively.

The shaped ligneous material obtained by the material of the eighth aspect of the invention also shows fine undulations which are characteristic of the surface of shaped wood by hydrostatic compression, indicating that it can be a valuable decorative material.

It should be stressed that the shaped ligneous material obtained by the above-mentioned method shows high dimensional stability against changing humidity and ambient temperature, since the synthetic resins contained in the surface layer of the densified wood effectively prevents moisture to penetrate into the wood. In order for a densified ligneous material to undergo volume relaxation at the temperature of ordinary use, it is absolutely necessary that moisture content increases, for some reason, beyond its fiber saturation point. Thus, the eighth aspect of the invention provides with a densified wood having permanently fixed compressed structure without recourse to treatment for fixing at high temperature.

In practice, all the aspects of the present invention described above are applied to soft coniferous wood such as cedar, larch, Japanese cypress, Port Orford cedar, Douglas fir, Oregon pine, Western hemlock and the like. Basically, however the present inventions should not be restricted to paticular species of woods.

D. Brief Description of the Drawings

FIGURE 1 is a cross-sectional figure of an example of compression forming apparatus to practice the hydrostatic compression forming of this invention.

FIGURE 2 is a cross-sectional figure of an example of compression forming apparatus equiped with an example of shaping jig to practice the hydrostatic compression forming of the third aspect of the invention.

FIGURE 3 is a plane figure indicating position on the ligneous shaped article(1) where thickness was measured to assess the effect of the sixth aspects of the invention.

FIGURE 4 shows a cross section of butt end of the ligneous shaped article to exhibit the effect of the sixth aspect of the invention. Figures (a) and (b) show the cross section before and after the fixation of the compression state, respectively.

FIGURE 5 is a plane figure of grain on the surface of a plank sawn out from a decorative shaped ligneous material obtained by the eighth aspect of the invention.

E. Description of the Preferred Embodiments

The invention is illustrated in more detail by reference to the following examples. However, the present embodiments are to be considered in all respects as illustrative and not restrictive. In the embodiments, unless otherwise indicated, the percentage of moisture content is by weight. The preparative recipes of impregnation liquids are by weight as well. Fundamental properties of wood such as surface hardness and so forth were measured according to the method of Japanese Industrial Standard JIS Z 2101-1994. Further, the degree of fixation of compressed state is indicated by the recovery ratio meaning how much percentage of decrease by compression in terms of cross-sectional area or thickness in the direction of compression is recovered by relaxation, which is calculated by Equation 1 or 2.

EXAMPLE 1

The first aspect of the invention is explained referring to FIG. 1 which shows an example of the apparatus for practicing hydrostatic compression forming. The apparatus 40 is equipped with a pressure vessel 41, a heater 42, a water tank 43 and a pump 44. Thermostat known in relevant industry may be equipped on the heater 42, though not shown in FIG. 1. Further, the reference numeral 45 is for a drain valve furnished to the vessel 41, 46a for a pressure-releasing valve, 47 for a cover of the vessel, 49 for a gas cylinder containing nitrogen which is substitutional by an air compressor in certain cases, 48 for cramp furnished to vessel for tight-sealing.

As many as 20 pieces of raw bolts of Japanese cedar with bark and its size being about 140 mm-160 mm in the diameter at the butt end and 2000 mm in the length and its average water content being 120% were treated for drying to reduce average moisture content down to 50% in the atmosphere of steam with the pressure of 1.0 kg/cm^2 G at 104 ℃ for 3 days. Among these dried bolts, 10 pieces were selected randomly to be daubed with a polychloroprene based adhesive for wood (commercial name; Bond G 17, manufactured by Konishi Co.

Limited) on the both cut ends and semi-dried at about 100 ℃, then a polyvinylidene chloride film with the thickness of 20 microns commercially used for food packaging was glued on the layer of said adhesives, and the film at both cut ends was bound on the bolt by means of a heat-resistant rubber string, respectively.

Then, aftersoftening these bolts by heating in an air oven at 95℃ for 3 hours, the bolts were loaded in a pressure vessel 41 as shown by FIG.1 with the inside diameterof 900 mm and the length of 3000 mm, and a cover 47 was closed. Then hot waterat 95 ℃ was filled by using a pump 44. And then, hot water was pumped in forabout 10 minutes until the pressure reached to 25 kg/cm² G. After keeping the pressure at aforesaid level by means of a relief-valve 46a set at 25 kg/cm² G for 10 minutes, the pressure was released and hot water was then returned to a water tank 43, and then the bolts were cooled spontaneously to ambient temperature.

The diameter of bolt at this stage after applying hydrostatic compression was smaller by 5% than that before treating. The bark was partially peeled off from the ligneous part. The bolts treated as described above were loaded in a dryer working at constant temperature with the size of 2000 mm in the inside width, 2000 mm in the inside depth and 2000 mm in the inside height, respectively, then dried at 80℃ under the control on moisture of atmosphere inside at 80% until the average moisture content reached to 20%.

By observing the shaped ligneous material obtained as aforesaid, cracking by drying was noticed on the side surface of 4 pieces out of 10 bolts.

In comparison to EXAMPLE 1, another 10 pieces of the bolts with moisture content of 50% was dried in the same dryer under the same condition as EXAMPLE 1 until the average moisture content reached to 20%. Cracking by drying was noticed on the surface of 9 pieces out of 10 bolts by observation. The data indicates an advantage of hydrostatic compression forming by the first invention on the improvement in physical properties of wood, enabling to save the aforesaid karfing on drying logs by adopting the hydrostatic compression.

EXAMPLE 2

A bolt of Japanese cedar with the size of 150 mm in the diameter at the top end and 1000 mm in the length, with its bark being chipped off, was wrapped with a commercial polyester film of 100 microns in the thickness, and pinholes were opened on the film. Then, the bolt was dried for 3 days in an air oven kept at 110 ℃ , resulting in decrease in the moisture content to 37%. The bolt was taken out of the dryer to use as a primary wood for hydrostatic compression.

Both cut ends of bolt were daubed with a 20% solution of polychloroprene in methylene chloride and semi-dried, then a polyvinylidene chloride film used cmmercially for food packaging was glued on the both ends to cover, and then the film was bound on the bolt at each end by a heat-resistant rubber string.

Though the covering of cut ends with polyvinylidene chloride film is effective in preventing water from penetrating into wood, it is not always a substantial part of the invention. The covering is necessary when higher pressure is required as in the case where the bolts or logs are to be compressed up to the heart wood. When compression is required to be limited to the peripheral part or the sap wood, the liquid pressure needs not to be too high. Treating the end surfaces with heat-resistant adhesives can be enough in such case.

Next, the bolt was loaded in a pressure vessel 41 as shown by FIG.1 before the temperature of bolt being lowered below its softening temperature, and hot water controlled at 95℃ was pumped in. When the air inside was completly replaced by hot water, pressure-releasing valve 41 was closed. No sooner closing the valve 46 than the inside pressure rose at a dash to 8- 10 kg/cm^2G. The pressure stayed in the region for a while and then rose rapidly to 30 kg/cm^2G, and the relief-valve 46a functioned at this moment, resulting in keeping the pressure in the vessel constant by balancing of the discharging speed from the valve 46a and the pumping speed of hot water.

At this stage, if the compressed bolt were taken out of the vessel after stopping and discharging of hot water, a shaped ligneous material by the first invention will be obtained by natural cooling and drying as described in EXAMPLE 1.

In this EXAMPLE 2, however, the pumping in of hot water was replaced by pumping in of cold water just at the time when the inside pressure reached constant value at 30kg/cm²G. And the temperature of discharged water was brought down to 32℃ in 15 minutes after the switching of water supply while the inside pressure being kept constant. As the temperature hardly changed since then, pumping was stopped in 60 minutes after the temperature of discharged water reached 32 ℃, then the shaped ligneous material by the fourth aspect of the invention was taken out of the vessel.

The resulting shaped material was compressed by 50% in terms of the ratio of cross-sectional area before and after the hydrostatic compression forming. The side surface of the shaped material was totally uneven, and irregular furrows was noticed all over the surface, showing an external appearance resembling that of a so-called fancy log.

The shaped material fixed in its compressed state by quenching does not bring about the volume relaxation in the ordinary environment, as the softening temperature of the material is high enough to hinder rebounding. The stability improves as the compressed wood is further dried.

EXAMPLE 3

A bolt of Japanese cedar with the size of 150 mm in the diameter at the top end and 600 mm in the length, with its bark being chipped off, was dried in the same manner as in EXAMPLE 2, resulting in the moisture content of 25%. Then both cut ends of bolt were cleaned with acetone and were coated with a commercial silicone coating (Toray Dow Corning Silicone PRX 305RTV Dispersion). Coating was repeated three times with about 1 hour of interval followed by curing at ambient temperature for 3 days.

Next, the bolt was loaded in a pressure vessel shown in FIG. 1, then the vacancy inside was filled with silicone oil. And the vessel was closed with cover 47 using clamp 48, then heated to 100 ℃ of the inside temperature by means of metallic heater 42. Then, the vessel was pressurized to 15 kg/cm^2G by injecting nitrogen gas from the cylinder 49. And then, the vessel was heated to 160 ℃ of inside temperature and maintained for 60 minutes while keeping the pressure constant, then the contents of vessel was cooled down to the room temperature.

The shaped ligneous material obtained as above-mentioned by the fifth invention was compressed by 52% in terms of the ratio of volume before and after the hydrostatic compression forming. The side surface of the shaped material was uneven similar to that obtained in EXAMPLE 2, and showed an external appearance resembling to a fancy log. The surface hardness increased up to 1.5 kgf/mm^2. Further, a test piece in the shape of a disk sawn off from the material showed only a small dimentional change when immersed in hot water of 90 ℃ for 20 minutes to assess the fixation of compressed state.

EXAMPLE 4

The third aspect of the invention is explained referring to FIG. 2 which illustrates an example of the apparatus equipped with an example of a shaping jig for practicing the hydrostatic compression forming.

The apparatus 20 is equipped with a pressure vessel 21, a wood-pushing arm 22, a water tank 23 and a pump 24. The pump 24 raises the pressure of a pressurizing liquid L , in turn a primary wood 10 is compressed by the hydrostatic pressure of liquid. A shaping jig 30 is installed inside of a shaping part 26 of the apparatus 20. A compressed wood 10A is pushed into the shaping jig 30 when the wood-pushing arm 22 is pushed from outside of a cover 27. By opening a cover 28, the compressed wood 10A as loaded in the jig 30 is taken together out of the apparatus 20.

A bolt of Japanese cedar with bark and its size being 150 mm in the diameter at top end, 165 mm in the diameter at butt end, 1000 mm in the length and its moisture content being 95% was dried in the atmosphere of steam of 1 kg/cm²G at 103-105 ℃ for 5 days, resulting in decrease in the moisture content to 40%.

The bolt was taken out of the dryer, and the both ends of the bolt were daubed with the same adhesives as used in EXAMPLE 1, then the same film and string were applied as well. After 2 hours of heating in an air oven controlled at 90℃, the bolt was loaded in the pressure vessel 21 shown in FIG. 2, then the cover 27 and 28 were closed. Then, hot water of 90℃ was pumped in the vessel by means of the pump 24 until the inside pressure raised to 25 kg/cm²G.

At this stage again, if the compressed bolt were taken out of the apparatus 21, a shaped ligneous material by the first aspect of the invention will be available after natural cooling and drying as described in EXAMPLE 1.

In the EXAMPLE 4, however, the compressed wood 10A was pushed into the shaping jig 30 by means of the wood-pushing arm 22 under the water pressure controlled at 25 kg/cm²G, then pumping was stopped to release the pressure and to drain hot water. As the result, the compressed wood 10A was pressed against the inside wall of the shaping jig 30 due to expansion caused by partial relaxation of the volume. Then, the compressed wood 10A as loaded in the jig 30 was taken out of the apparatus 20 and dried in an air oven at 110℃ for 2 days. And then, the shaped ligneous material by the third invention was easily taken out of the jig 30, as the material shrank slightly by drying .

The shaped ligneous material in a shape of column as obtained above has high accuracy in circular cross section, and the surface hardness was remarkably improved comparing with that of a primary wood.

An advantage of this method is that pillars with circular or polygonal cross-section can be easily produced. It should be noted that the production of similar shaped material by means of compression in molds is extremely difficult and expensive.

EXAMPLE 5

The forming method by the sixth aspect of the invention is illustrated below.

Preparation of densified wood(No. 1);

A flat grain board of Japanese cedar with the size of 900 mm in the length, 50 mm in the thickness in radial direction, 150 mm in the width in tangential direction and with moisture content of 23%, was heated in an autoclave by using saturated steam of 2 kg/cm^2G for 60 minutes. Then, the softened board as above-mentioned was taken out of the autoclave and compressed in radial direction between a pair of hot plates controlled at 120℃, until the board decreased in thickness down to 22 mm. The hot plates were then chilled by circulating water in their cooling pipes, while maintaining the tightening pressure, until the board temperature at its center came down below 30℃. And a densified wood (No. 1) with its compressed state temporarily fixed was obtained.

A test piece with the size of 300 mm in the length, 22 mm in the thickness in radial direction and 102 mm in the width in tangential direction was machined out of the wood (No. 1). To observe transformation accurately, the measurment points were positioned in the manner of a grid having 3 points (A, B, C) placed in the tangential direction and 3 points (No. 1, No. 2, No. 3) in the fiber direction, giving 9 points in total.

Compact packing of heat-resistant hard particles;

A vessel made of stainless steel was used for heat treatment in the experiment. The vessel was of a cylindrical type with 2 end plates bolted to the cylinder through a flange and with the size of 105 mm in the inside diameter and 400 mm in the length. It should be noted that no packing was used at the flange so that the vessel could retain hard particle inside but gases like steam and air could freely go into and out of the vessel.

The vessel, fixed with lower end plate, was placed upright and alumina powder with average particle size of 0.5 mm (Morundum A-40, No. 36, manufactured by Showa Denko Co. Ltd.) was put in with the depth of about 50 mm. The test peice aforesaid was placed along the center line of the cylinder. The vacancy in the vessel was then filled with the alumina powder while the side wall of vessel was hammered for compact packing of the powder.

In practice at large scale, it is preferable for the board to separate each other at a distance of a few centimeter to avoid contacting. Generally, average particle size of 0.3-2 mm is desirable in case of fixing a densified wood with smooth surface. Natural sand with relatively uniform particle size, synthetic inorganic particle like silica and alumina and commercial alumuna abrasives can be used as well.

Filling and hammering was repeated several times until no more improvement in packing appeared possible. Finally the upper end plate was bolted to the vessel in such way as to squeeze the powder inside. The side wall of vessel was hammered again, and further bolting was done to better squeeze the content.

As an alternative for compact packing, a vibration rod can be used to have the particles vibrate by inserting it into the particles and to add some more.

Heat treatment;

The vessel filled as above-mentioned was placed in an autoclave and heated in the saturated steam at 175 ℃ for 1 hour. The steam pressure was then gradually reduced to atmospheric pressure and the whole was left to cool. The temperature for heating is desirable in the range of 140-190℃ in case of wet-heating by means of steaming, for example, and in the range of 180-250 ℃ in case of dry-heating by means of hot dry air, for example.

The shaped ligneous material by the sixth aspect of the invention as above-mentioned was taken out of the vessel. The material showed weight decrease of 5.8% due to loss of moisture. Then, the thickness of material was measured at the same 9 points asin FIG.3 and the results were given in Table 1.

Measurement of the degree of fixation;

The test piece of shaped material fixed as above-mentioned was immersed in a water bath controlled at 95 ℃ for 60 minutes. The test piece was then dried completely by heating in an air oven at 105 ℃ for 3 days. The thickness of the dried test piece was measured at the same 9 points as aforesaid. Percentage recovery was calculated by using the equation 1 and the results were given in Table 1.

Equation 1

$$\text{Percentage recovery} = \frac{t_2 - t_1}{t_0 - t_1} \times 100$$

t_0 : thickness of test piece before compression

t_1 : thickness of test piece after fixation by heat treatment

t_2 : thickness of test piece after soaking and drying

Slightly negative values for recovery are due to complete drying of the soaked test piece, which has caused an excessive shrinkage in the radial direction. This should be taken actually as the proof of complete fixation of the compression state.

EXAMPLE 6

Preparation of densified wood (No. 2);

A bolt of Japanese cedar with bark and its size being 170 mm in diameter at top end, 950 mm in the length was dried in the same manner as in EXAMPLE 4 but for 2 days, resulting in decrease in the water content to 37%. Then, both cut ends were treated in the same manner as in EXAMPLE 1. Then, the bolt was heated in an air oven at 90℃ for 2 hours.

And then it was placed in a pressure vessel of vertical cylinder type shown in FIG. 2 and filled with hot water of 95℃. On closing the lid, cold water was pumped into the vessel from the bottom at the rate of 2 litters a minutes. The inside pressure reached 30 kg/cm²G in 5 minutes, then cold water was continuously supplied while the pressure was retained by means of the relief-valve until the drain temperature reached to 30 ℃ in 15 minutes. Pumping of cold water was continued for another 90 minutes before taking out the compressed bolt.

After removing the bark, the bolt was left in a dry environment for a week. The densified wood (No. 2) obtained as above-mentioned had the characteristic appearance resembling a fancy log. The cross sections of densified wood (No. 2) was photo-copied on a paper to measure the area. By the measurement, average decrease in the area by 48% was obserbed due to the compression.

Fixation by heat treatment;

The densified wood (No. 2) was split along the fiber direction and the split surface of a resulting piece was finished with a plane. By sawing the piece at right angle to the fiber direction, a test piece of 220 mm in the length was prepared. The cross section of the test piece is shown in FIG. 4(a), wherein the letter A marked on the section means it is the butt end.

Next, the test piece was treated in the same way as described in EXAMPLE 5 by using the same vessel, alumina and autoclave as described in EXAMPLE 5 to obtain the shaped ligneous material by the sixth aspect of the invention.

Generally, average particle size of 2-4 mm is desirable in case of fixing a log for producing sawn lumber.

The butt end after the heat treatment was photo-copied to measure the cross-sectional area. Comparison between FIG 4(a) and 4(b) shows that details of the section profile retained to hold a similar figure to that before treating except that decrease in the area by 1.6% occurred due to the treatment. It was shown that no volume relaxation or expansion of test piece took place during the course of fixation by steam heating. The decrease in the weight by 5.4% was observed in the treatment.

Measurement of the degree of fixation;

The test piece was treated in the same condition as described in EXAMPLE 5 by using the hot water bath and the oven. The measurement of the cross section showed no change in the area through the treatment. That is, the percentage recovery calcurated by the equation 2 has turned out to be zero.

Equation 2

$$\text{Percentage recovery} = \frac{s_2 - s_1}{s_0 - s_1} \times 100$$

s_0 : cross-sectional area of test piece before compression

s_1 : cross-sectional area of test piece after compression and fixation

s_2 : cross-sectional area of test piece after soaking and drying

By applying the above mentioned method to a log, a sawn lumber and the like as a primary wood in replacement of a compressed wood, a residual stress existing in logs and sawn lumber can be removed. In case of this seventh aspect of the invention, the temperature of heat treatment corresponding to fixation treatment is desirably in the range of 70-150 ℃.

EXAMPLE 7

The forming method by the eighth invention is illustrated below.

Drying of a primary wood;

Two pieces of log with the length of 800 mm were cut out from Japanese cedar with bark, with the size of 150 mm in the diameter and 1800 mm in the length, to use as a primary wood in hydrostatic compression and as a control, respectively. The primary wood was dried in the atmosphere of steam of 1 kg/cm^2G at 105℃ for 3 days. After drying the bark was removed by means of a metal scraper. Cracking by drying with maximum width of around 1 mm and radially directed was observed at the heart part of both ends, as well as small cracks in the fiber direction on the side surface. The moisture content was calculated to be 29% by using the decrease in weight after drying. The weight after drying was 7.34 kg.

Generally, it is desirable to dry down approximately to the fiber saturation point (moisture content of about 28%) for making impregnation easy, though excessive drying below that point is not desirable due to frequent generation of surface cracks.

Preparation of impregnation liquid;

A dope of polymethyl methacrylate for impregnation was prepared by dissolving 30 parts of polymethyl methacrylate of a commercial grade into 100 parts of commercially available methyl methacrylate of extra pure grade. After cooling the solution, 2 parts of benzoil peroxide was added. And further, 0.2 parts of N,N-dimethyl aniline was added as a promoter for polymerization just before using.

Generally, the volume of polymer to be dissolved in a dope can be adjusted to make viscosity of the dope suitable for filling the cracks generated on a primary wood. The impregnation liquid can contain any wood preservatives as long as they are soluble in the liquid.

Resin impregnation;

The dried log above-mentioned was loaded in the pressure vessel of vertical type with the inside diameter of 200 mm, then the dope was poured in the vessel up to 1000 mm in the depth. The log with buoyancy was submerged into the dope by using a weight. Then, the vessel was tight-sealed and the inside pressure was lowered by a vaccum pump to 50 mmHg and kept at this level for 5 minutes.

Next, nitrogen was injected from gas cylinder to impregnate the dope by pressurizing for 10 minutes. And then, the vessel was opend to recover the dope and the log was taken out to wipe off the extra dope remained on its surface. The polymerization of methyl methacrylate in the impregnated dope was completed by heating the log in the atmospher of nitrogen at 30 ℃ for 1 hour and at 90℃ for another 1 hour, succesively. Total weight of log after impregnation was 7.92 kg. Nitrogen can be replaced by air in case of the monomer in the dope is polymerizable even in the presence of oxygen or moisture in the air.

Hydrostatic compression;

The log, after treatment as above-mentioned, was loaded in an autoclave of vertical type filled with hot water of 95 ℃. Then the autoclave was tight-sealed and heated at 95 ℃ for 30 minutes. After stopping the heating, the valve at bottom of the autoclave was opened for injecting cold water at 15℃ by means of pump. The log was compressed by the hydrostatic pressure at 26 kg/cm^2G in the same manner as in EXAMPLE 2, and in consequence, the temperature of water was brought down to 30 ℃ in 15 minutes. And the operation was continued for another 60 minutes. Then, the shaped ligneous material by the eighth aspect of the invention was taken out of the autoclave.

The cross-sectional area at the both ends of log were reduced to 57% in the average by compression. The side surface of the log had uneven and external appearance like fancy log was observed. Penetration of water during the hydrostatic compression was concluded to be minimal, as the total weight of the shaped material was 7.95 kg.

Test for physical properties;

A 20 mm thick board was prepared from the above-mentioned log by sawing and planing. A non-natural beautiful grain appeared on the surface of the board reflecting the internal deformation of annual rings by hydrostatic compression. Table 2 summarizes the results of the measurement on flexural strength and other physical properties conducted on the test piece with the dimension of 20 mm in the width in tangential direction, 20 mm in the thickness in radial direction and 320 mm in the length in fiber direction cut out of the above-mentioned board. The hardness and abrasion data are shown also in the table. It was concluded that the shaped ligneous material obtained by the eighth aspect of the invention as above-mentioned was superior to a dried primary wood in the all fundamental properties.

The present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The scope of the invention is to be indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

The entire disclosure of Japanese Patent Application No. 8-283181 filed on October 4, 1996 and Japanese Patent Application No. 9-60365 filed on March 14, 1997 and Japanese Patent Application No. 9-106027 filed on April 23, 1997, including specification, claims, drawings and summary are incorporated herein by reference in its entirety.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1 A method of processing wood comprising:

(a) a step wherein a primary wood, its water content being adjusted in the range of 10-80wt%, is brought into softened state, and

(b) a step wherein the softened wood so obtained as above is compressed for forming with hydrostatic pressure by means of a liquid as pressurizing medium.

2 The method according to claim 1, wherein said (a) step for softening and said (b) step for compressing with hydrostatic pressure are conducted concurrently by using a pressurizing liquid of which temperature has been elevated to at least the softening point of the primary wood.

3 A method of processing wood comprising:

(a) a step wherein a primary wood, its water content being adjusted in the range of 10-80wt%, is brought into softened state, and

(b) a step wherein the softened wood so obtained as above-mentioned is compressed for forming with hydrostatic pressure by means of a liquid as pressurizing medium, and

(c) a step wherein the compressed wood so obtained as above-mentioned is treated after the (b) step with at least one fixation means of compressed state.

4 The method according to claim 3, wherein said (a) step for softening and said (b) step for compressing with hydrostatic pressure are conducted concurrently by using a pressurizing liquid of which temperature has been elevated to at least the softening point of the primary wood.

5 The method according to claim 3, wherein said (c) step for fixing compressed

state includes;

(1) loading the compressed wood in a shaping jig placed under the hydrostatic pressure, and

(2) reducing the liquid pressure for allowing the compressed wood to relax its compressed volume and to press its surface against the inside wall of jig for forming , and then

(3) holding the compressed wood in the jig for fixing compressed state of the shaped wood so formed as above-mentioned.

6 The method according to claim 5, wherein said (a) step for softening and said (b) step for compressing with hydrostatic pressure are conducted concurrently by using a pressurizing liquid of which temperature has been elevated to at least the softening point of the primary wood.

7 The method according to claim 3, wherein said (c) step for fixing compressed state includes lowering the liquid temperature below the softening point of the primary wood while the liquid pressure is maintained.

8 The method according to claim 7, wherein said (a) step for softening and said (b) step for compressing with hydrostatic pressure are conducted concurrently by using a pressurizing liquid of which temperature has been elevated to at least the softening point of the primary wood.

9 The method according to claim 7, wherein said (c) step for fixing compressed state is conducted by exchanging the said liquid of elevated temperature for cold liquid while the liquid pressure is maintained.

10 The method according to claim 3, wherein said (c) step for fixing compressed state includes elevating the liquid temperature to the range of 140-180 ℃ while the liquid pressure are maintained.

11 The method according to claim 10, wherein said (a) step for softening and said (b) step for compressing with hydrostatic pressure are conducted concurrently by using a pressurizing liquid of which temperature has been elevated to at least the softening point of the primary wood.

12 The method according to claim 3, wherein said (c) step for fixing compressed state includes;

(1) loading the compressed wood in a vessel, and

(2) filling up all the space left inside the vessel with heat-resistant hard particles in the state of compact-packing, and

(3) heating the contents of the vessel while retaining the state of compact-packing for fixing the compressed state.

13 The method according to claim 12, wherein the particle size of said heat-resistnt hard particles is in the range of 0.3-4 mm.

14 The method according to claim 12, wherein said filling with heat-resistant hard particles in the state of compact-packing is conducted by means of vibration.

15 The method according to claim 12, 13 or 14, wherein said heating while retaining the state of compact-packing is carried out either by dry-heating in the range of 180-250℃ or by wet-heating in the range of 140-190℃.

16 The method according to claim 12, wherein said (b) step for compressing is conducted by means of either a shaping jig or a mold.

17 A method for eliminating residual stress existing in a primary wood comprising:

(a) a step wherein a primary wood in a shape of log or sawn lumber is loaded in a vessel, and

(b) a step wherein all the space left inside the vessel is filled up by heat-resistant hard particles in the state of compact-packing, and

(c) a step wherein the contents of the vessel is heated while retaining the state of compact-packing.

18 A hydrostatic compression method of processing wood comprising:

(a) a step wherein a dried primary wood is impregnated with a liquid containing at least one kind of vinyl monomer as a principal ingredient, and

(b) a step wherein the vinyl monomer impregnated in the primary wood is polymerized for producing a ligneous material containing synthtic resin in a wood, and

(c) a step wherein the ligneous material is compressed by pressurizing liquid of higher temperature above the softening point of the primary wood, and

(d) a step wherein the ligneous material so compressed as above-mentioned is cooled down below the softening point of the primary wood while the liquid pressure is maintained.

19 The method according to claim 18, wherein said impregnation liquid contains vinyl monomer and at least one compound as principal components selected from the group consisting of polymer, pre-polymer and origomer of the vinyl monomer.

20 A ligneous material obtained by the method according to claim 1, 5, 7, 10, 12, 16, 17 or 18.

21. A method of processing wood substantially as herein described with reference to the Drawings and to the Examples.

22. Wood when processed by a method as claimed in claim 21.

DATED this 7th day of FEBRUARY, 2001

MYWOOD CORPORATION

by DAVIES COLLISON CAVE
Patent Attorneys for the Applicant

Tables

TABLE 1.

Position of measurement	Thickness after Compression	Thickness after Fixation	Thickness increase on fixation %	Thickness after hot water soaking	Recovery ratio %
A 1	21.6	21.9	1.4	21.2	-2.5
2	21.9	22.6	3.2	22.3	-1.1
3	21.7	22.3	2.8	22.0	-1.1
B 1	22.5	22.2	-1.3	22.1	-0.3
2	22.4	22.7	1.3	22.5	-0.7
3	22.2	21.8	-1.8	21.5	-1.1
C 1	21.9	21.9	0	21.3	-2.1
2	21.7	22.5	3.7	22.0	-1.8
3	21.5	22.5	4.7	22.0	-1.8

Note: Unit of thickness ; mm

t_0 = 50 mm

Table 2.

Fundamental properties	Shaped material of this invention	Dried primary wood for comparison
Dried specific gravity	0.71	0.40
Flexural strength (N/mm^2)	99	78
Flexural modulus (N/mm^2)	12300	7800
Surface hardness (kgf/mm^2)	1.26	1.05
Abrasion loss (mm)	0.17	0.36

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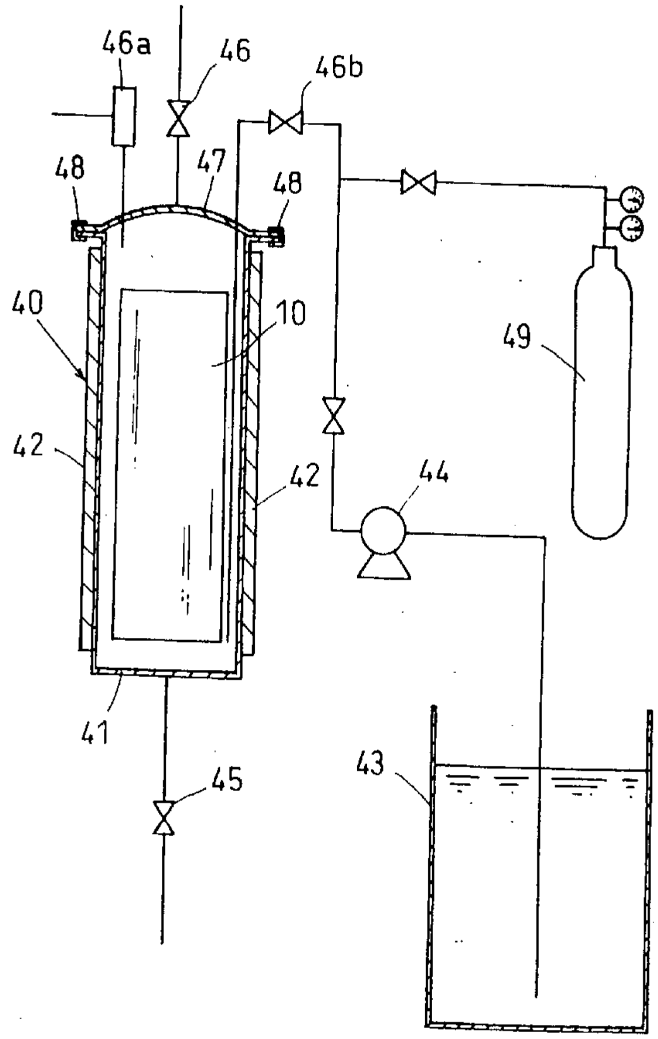
FIGURE1.



12 09 97 37504

FIGURE 2.

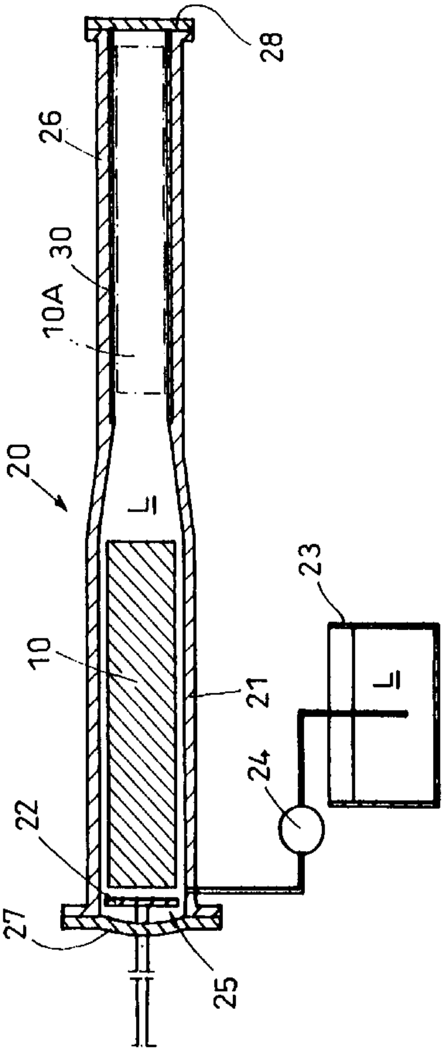


FIGURE 3.

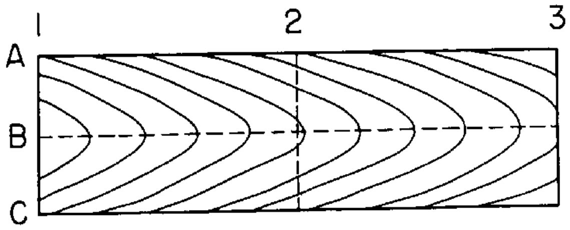
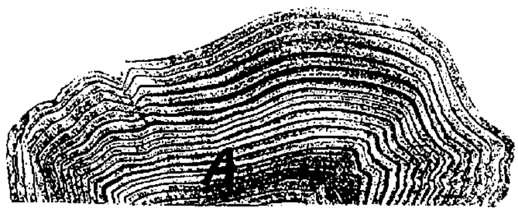


FIGURE 4.

(a)



(b)

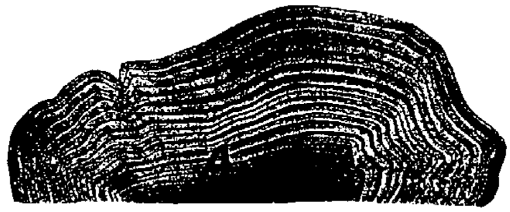


FIGURE 5.