March 15, 1949. G. G. HAVENS 2,464,391

ARTIFICIAL LIMB

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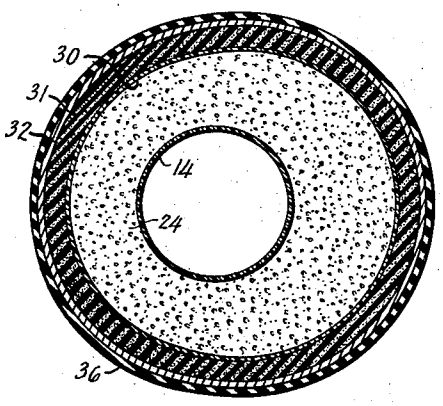

FIG. 2

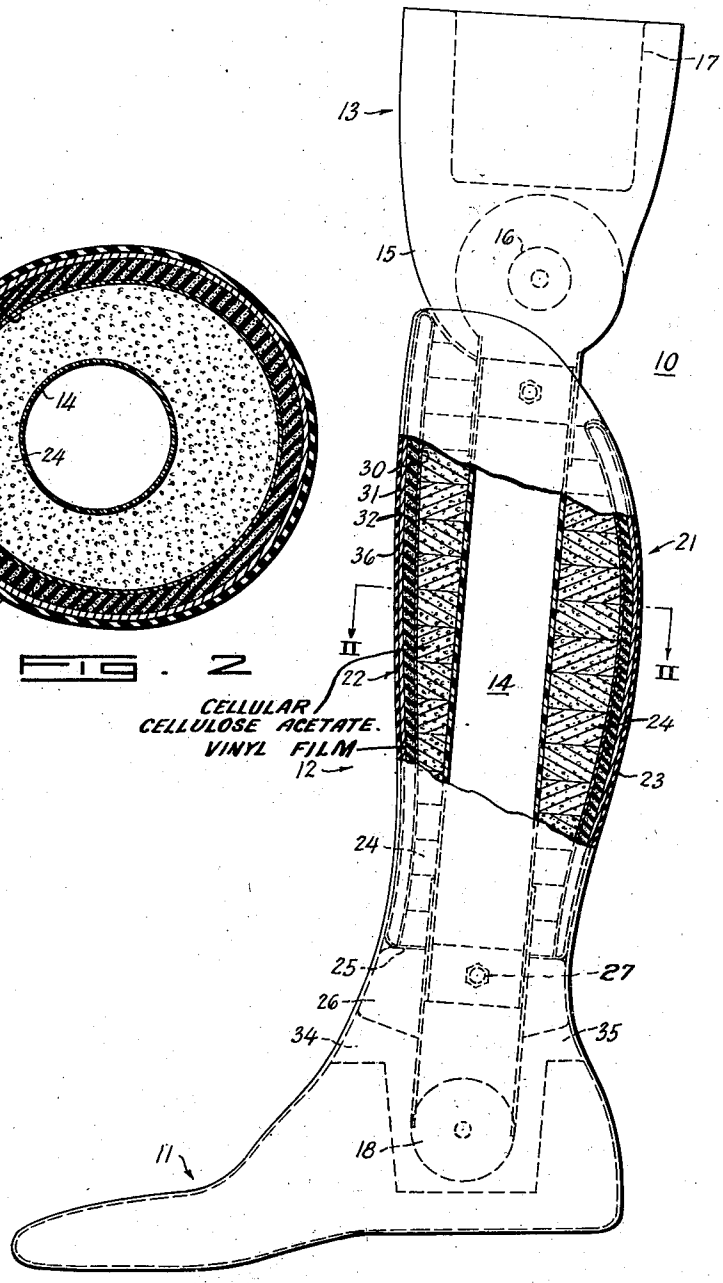

FIG. 1

Inventor

Glenn G. Havens

By

Walter J. Jason

Attorney

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Glenn G. Havens, San Diego, Calif., assignor to Consolidated Vultee Aircraft Corporation, a corporation of Delaware

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The present invention relates to improvements in artificial limbs and more particularly to an improved construction for a primary weight bearing prosthetic device.

An object of this invention is to provide an improved prosthetic device having a novel construction which renders it light in weight yet having the required strength for the purpose desired and which is adapted to absorb shock energy and endure sharp blows.

Another object of the invention lies in the provisions of a natural appearing shank prosthesis of improved construction having a high strength to weight ratio and which utilizes a simple column as the main supporting member covered with a fairing to lend shape to the shank.

A further object resides in providing a novel construction for a prosthetic device which permits the ready building of such devices in a variety of sizes to fit the individual amputee.

Other objects and features of the invention will be readily apparent to those skilled in the art from the following specification and appended drawings illustrating certain preferred embodiments of the invention in which:

Figure 1 is an elevational view of an artificial leg embodying the present invention, with a portion broken away to show the shank construction; and

Figure 2 is a cross-sectional view taken on the line II—II of Figure 1.

Referring now in detail to the drawings, an artificial limb embodying the present invention is designated by the numeral 10. The artificial limb 10, as illustrated, comprises a foot section 11, a shank section 12 constructed in accordance with the invention, and a thigh section 13.

The shank 12 comprises a weight bearing member which is a tubular element or column 14 formed of a high strength plastic to be described in detail hereinafter. The column 14 is connected, at its upper end, to the knee 15, in the thigh part 13 of the leg, by suitable pivotal means 16, the latter means effecting a knee joint or hinge. The particular construction of the knee joint 16 forms no part of the present invention; any hinge device which permits the shank 12 to freely rotate relative to the thigh 13 may be utilized. The thigh section 13 is provided with a recess or socket 17 and is adapted for use with above the knee amputations. Here also the particular construction of the thigh 13 forms no part of the present invention. It is contemplated that the invention could be applied to below the knee amputations with suitable provision being made for the connection between the shank 12 which embodies the invention and the person of the wearer.

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The column 14 is pivotally connected or hinged in a suitable manner, at its lower end, as at 18, to the foot portion 11 whereby the foot 11 is adapted to move relative to the shank 12. Again the particular construction of the foot 11 and of the hinge 18 forms no part of the present invention, the shank 12 is adapted to be used with a variety of foot constructions and to be rotatively connected thereto in a number of ways.

Disposed about the tubular or skeletal element 14 to give shape to the shank 12 is an enclosing element or cosmetic covering 21. The cosmetic covering 21 extends from adjacent the knee 15 to substantially the foot 11 and has the front or shin portion 22 and the rear or calf portion 23 thereof shaped to conform generally to the contour of a leg.

The cosmetic covering 21 embodies a sandwich construction which achieves a desired stiffness while maintaining a minimum weight. It is to be noted particularly that the cosmetic covering 21 is not designed to bear weight, its primary purpose is to provide a natural contour to the prosthesis and it is required only to have sufficient impact strength to withstand accidental blows. The weight of the wearer will be borne by the skeletal element 14.

The fairing material for the cosmetic covering 21 is comprised of a multiplicity of slabs or layers 24 of plastic foam disposed one upon the other for substantially the length of the column 14, which column 14 passes through openings provided in the individual slabs 24. The lowermost of the slabs 24 is adapted to rest upon ledge portions 25 provided by an ankle construction 26 suitably mounted at the lower end of tubular element 14 as by bolt 27. The remainder of the slabs 24, as illustrated, are laid one upon the other until the desired length of shank is attained. Each of the various slabs 24 is of a somewhat different size and configuration in order that when assembled a natural leg contour will be simulated. A suitable thermoplastic bonding adhesive or glue may be employed between the various layers 24 and between the lowermost layer and the ledge portions 25 of the ankle 26 to maintain the layers 24 in the position desired.

To assist in the maintenance of the various slabs 24 in assembled relation, a skin 30 formed of plastic is disposed about the exterior of the stack, the skin 30 being secured to the outer surface of the stack of slabs 24 by an appropriate

adhesive and being cured in position. The skin 30 has desirable impact strength and provides a hard surface which is resistant to sharp blows.

Disposed over and in surrounding relation to the skin 30 is a layer 31 of sponge rubber. The sponge rubber provides a tactual quality to the prosthesis and further serves to eliminate such noises as occur when the shank 12 strikes hard objects.

To provide a uniform and natural color to the prosthesis and to furnish desirable smoothness, a second skin 32 is applied to the shank 12. This second skin 32 is formed of a transparent plastic, to the interior surface of which, the surface adjacent the sponge rubber, there is applied flesh colored paint. A shank 12 is thus effected which is easily cleaned, which resists discoloration and which gives the translucent appearance of flesh.

To bridge the gaps 34 and 35 which exist between the ankle 26 and foot 11 a stocking 36 formed of rubber is drawn over the foot 11 and shank 12. It is understood, of course, that the stocking 36 is not necessary to the invention and need not be of a sufficient length to cover the entire shank prosthesis. It is provided primarily for esthetic purposes to cover the gaps at the point of connection of the shank 12 to the foot 11, though incidentally it serves to absorb shock of accidental blows. Any device which covers the gaps may be utilized or if desired the shoe worn may be modified to provide a bridge for these gaps.

From the above description of the construction of the shank 12 it is readily apparent as to how the length of a shank can be modified to lengthen or shorten it to accommodate different wearers. A tubular element 14 of desired length is first chosen and then an appropriate number of plastic foam slabs 24 is applied thereon to effect a shank having the required dimensions from ankle to knee. Having a prosthesis of the desired length, the skin 30 is cured thereon, as will be described, and a layer of sponge rubber applied over which is fitted the skin 32 having the appearance of flesh.

The compositions of the various plastics and plastic foam that may be utilized in the present invention will now be discussed.

The plastic foam slabs 24 as used here are formed of cellular cellulose acetate (which is cellulose acetate in an unoriented multicellular form). Cellulose acetate, as is well known, is a plastic made by treating cotton linters (cellulose) with acetic acid and acetic anhydride in the presence of a suitable catalyst such as sulphuric acid, zinc chloride, or phosphoric acid. This plastic is aerated to effect the unoriented multicellular form. Cellular cellulose acetate is readily workable and can be easily machined into desired shapes by the use of standard woodworking equipment. Thus the various slabs 24 mounted on the skeletal element 14 can be readily formed into shapes which when assembled simulate the human shank. Cellular cellulose acetate is adapted to be bonded to itself or to skins by standard glues. Cellular cellulose acetate has a high shear strength and a relatively high impact strength in view of its low density and is well adapted for use as a fairing in the fabrication of a shank as in the present invention.

It is understood that other plastic foams may be employed in effecting slabs for building up a shank 12 according to the present invention. For example, aerated styrene or the aerated synthetic rubbers such as butadiene acrylonitrile copolymers are adapted for use in the construction of a shank for they possess satisfactory impact strength and have the required low density.

The transparent enclosing skin 32 disposed over the sponge rubber layer is preferably a vinyl resin plastic such as vinyl chloride-vinyl acetate copolymer resin which is provided as a transparent film. The interior surface of this transparent film is covered with flesh colored paint as required by its use in this invention. It is contemplated that other transparent plastics such as cellulose acetate, cellulose nitrate, polystyrene or ethyl cellulose in film form could be utilized in the fabrication of the shank of the present invention.

Both the inner plastic skin 30 covering the slabs 24 and the column 14 are preferably formed of low pressure plastic laminates which laminates are comprised of an appropriate filler impregnated with a thermosetting resin. Two principal types of thermosetting resins are adapted for low pressure laminates. These are the unsaturated polyesters and certain of the phenolics.

The unsaturated esters are the reaction products of saturated and unsaturated polybasic acids (such as maleic acid, succinic acid, phathalic acid, citric acid, malic acid, fumaric acid) and saturated and unsaturated polyhydric alcohols (such as glycerol; polyglycerols; glycols such as ethylene glycol, butylene glycol or trimethylene glycol; polyglycols; pentaerythritol; sorbitol and mannitol). It is understood that the acids and alcohols herein named are merely representative of the polybasic and polyhydric alcohols that may be used. As initially prepared, the unsaturated polyesters contain a number of unsaturated ethylenic groups which upon polymerization form cross-linked, three-dimensional structures. The unsaturated polyesters are applied as low molecular weight viscous products which may be converted through polymerization to a solid form by the application of heat or a catalyst or by a combination of both. These resins are anhydrous, i. e., containing no water and producing none; and because no potentially volatile material is split off in the form of a by-product during the cure the unsaturated polyester resins may be processed at low pressures.

The phenolic resins that can be utilized in the present invention are those which are the reaction products of a phenolic compound such as phenol, creosol, xylenol, and resorcinol, with an aldehyde such as formaldehyde or furfural in the presence of a suitable alkaline catalyst (which may be ammonia, caustic alkali, or such amines as methylamine, aniline, and benzylamine), with the reaction taking place at a moderate temperature of about 195° F. Since a thermosetting resin is required the molecular ratio of the phenolic to the aldehyde must be less than 1 to 1. As is well known when the ratio is greater than 1 to 1 a thermoplastic resin is obtained.

It has been found that phenolic resins of the type described when modified with a thermoplastic component such as a synthetic linear condensation superpolyamide are particularly well adapted for use in low pressure laminating.

As has been stated, a low pressure plastic laminate in addition to a thermosetting resin comprises, as a component, a filler. The functions of a filler are several; it acts as a carrier for the resins which are in a liquid or semi-monomeric state; it improves the physical characteristics of the unsupported resin, particularly with respect to flexural, impact and compressive

strength; and it imparts design and decorative effect for specific applications.

Where high strength to weight ratios are required, as in the present invention, such fillers as fibrous glass (in woven cloth or mat form), synthetic polyamides, regenerated cellulose having a highly oriented molecular structure, linen, and high strength viscose rayon yarn may be used. Of these fillers it has been found that the fibrous glass type fillers are the most satisfactory for the particular use required by this invention because they produce laminates of exceptionally high strength with excellent impact resistance. Further, the filler is flame proof and is not affected by water or fungi. The fibrous glass is preferably provided in the form of continuous filament all-glass cloths and warps or as uni-directional cloths, i. e., cloths with a glass warp and cotton fill. Before impregnation with a resin the lubricant which was added in the manufacturing process to the fibers to facilitate weaving is removed by heat treating, that is—if it has not already been pretreated by the manufacturer, to obtain maximum adhesion of the resin to the glass.

To effect a lamina the fillers and thermosetting resins are combined in any well known manner as by brushing or as by running the filler in sheet form through a dip tank filled with the desired impregnating resin and then passing the wet sheet through squeeze rollers to remove the excess resin. The impregnated filler is then molded into the desired shape by the use of any well known molding methods such as the steam inflated rubber bag method, the autoclave blanket method wherein a vacuum and steam heat is utilized, or by spirally wrapping cellophane about a sheet disposed on a mandrel and relying on the shrinkage of the cellophane during the heat cure to supply the desired forming pressure.

The following example will serve to illustrate the various steps taken in effecting laminates desirable for use in constructing the tubular element **14** and the protective skin **30** covering the plastic foam slabs **24**.

An impregnating bath solution comprising a modified phenolic resin is first prepared. This particular resinous compound comprises as one ingredient, an alcohol soluble phenol-formaldehyde condensation product condensed in the molecular ratio of from 1 mol phenol to 1 to 2 mols formaldehyde basically catalyzed and neutralized in a manner well known in the art, and as a second ingredient a thermoplastic modifier which is a condensation product of a carboxylic acid (having the general formula $COOH(CH_2)_nCOOH$) and a methyl diamine (of the general formula $NH_2(CH_2)_nNH_2$) or urea or thiourea, with the specific condensate product utilized in this invention being formed from adipic acid and hexamethylene diamine.

These two ingredients, the phenolic resin and the condensate product of adipic acid and hexamethylene diamine are combined in a common solvent, a monohydric alcohol, with the phenolic condensate being in the proportion of 3 parts thereof to 1 part of the adipic acid-hexamethylene diamine condensate, and with the solid contents of the condensates to the alcohol being adapted to vary from 20 to 40% solids.

In the present example the bath is comprised of 64% ethyl alcohol and 36% of the resinous solids.

The filler used in this embodiment of the invention is a bi-directional all-glass cloth treated

to remove weave lubricant. This particular cloth is used because it provides desirable strength in both crosswise and lengthwise directions. The glass cloth is passed through the impregnating bath and then threaded between rubber rolls to squeeze out the excessive resinous compound taken on by the glass fabric. This immersion of the fabric in the solution occurs at room temperature. The impregnated fabric is then stored at room temperature to permit the ethyl alcohol to evaporate or the drying process could be accelerated by placing the fabric in an environment of elevated temperature. With the evaporation of the alcohol the weight ratio between the solid resin compound and the fibrous glass fabric will be about 27% of the solid resin to about 73% of the glass fibers. The thickness of the impregnated fabric will be about .012 inch.

The impregnated sheet is then formed into a column by the use of a suitable tube rolling machine wherein the sheet is wrapped about a roller. A sufficient length of sheet is provided to effect a tubular element having a wall thickness of 0.125 inch which was found to be satisfactory for the present invention. The edge of the final lap is moistened with alcohol to prevent the layers loosening after removal from the machine. Curing pressure is applied to the tube by spirally wrapping a 1½ inch strip of cellophane therearound, the cellophane shrinking during the heat cure. The heat cure involves placing the wrapped tube in an oven at a temperature of 330° F. for a period of about 30 minutes.

The ratio of the solid resin to the fibrous glass in an impregnated sheet can be varied over a substantial range and a satisfactory laminate still be obtained. It has been found that the solid resin content may range between 20 and 35% and the fibrous glass between 80% and 65%. In the preferred embodiment detailed about 27% of solid resin was used.

The curing pressures employed in carrying out the invention may vary from 2 p. s. i. to 80 p. s. i.; at 2 p. s. i. contact is assured; at pressures above 80 p. s. i. there will be a tendency to create conditions of resinous fluidity that may cause the resin to distribute itself unevenly throughout the laminate.

The curing temperatures may range from 280° to 350° F. The curing time varies according to the thickness of the fabric and the curing pressure employed. The curing time of an impregnated fabric increases in proportion to its thickness due to the low conductivity of the impregnating materials which prevents quick uniform heating throughout the mass of the material.

A laminated tube or shaft **14** built in accordance with the process above outlined and having the composition set out will have a high strength to weight ratio and will possesss high columnar strength.

A skin **30** is applied to a stack of cellular cellulose acetate slabs **24** by brushing a suitable glue upon a side of an impregnated sheet, forming the sheet about the assembled stack, and curing in an autoclave, air being exhausted to a vacuum pressure of 15 p. s. i. and a temperature of 330° F. being supplied for about 10 minutes.

After the skin **30** has been applied to the slabs **24** the sponge rubber layer **31** is fitted thereto using a suitable glue to effect adherence. A transparent vinyl film **32** having its interior surface painted as described is then adhered to the sponge rubber layer **31** utilizing a suitable

glue. Upon application of this final skin the cosmetic covering 21 is completed. It is noted that the cosmetic covering 21 may be constructed either on the tubular element 14 or upon a suitable mandrel. In the present example the cosmetic covering 21 is built up utilizing a mandrel. When the cosmetic covering 21 has been completed the mandrel is removed and the covering is slipped over the tubular element 14 and the ankle construction 26 mounted to the tube to hold the covering in place. The tubular element 14 is adapted to be secured to attachment fittings located at the knee 15 and foot 11 to complete the assembly.

This invention exemplifies a shank prosthesis having high strength and low weight and which is adapted to be constructed at minimum cost. The provision of a single weight bearing element as a core or skeleton upon which a light weight shape determining fairing is disposed, effects a type of construction which permits of the ready making of any particular size of artificial limb to meet the demands of the individual amputee.

The materials comprising the skeletal element and the cosmetic covering supported thereon have been selected because of their providing the required strength while still being light in weight.

It is readily apparent that the construction described for the shank prosthesis 12 is as well adapted for the making of other primary weight bearing prosthetic devices such as a forearm. Here the principal components would be a simple column acting as the main supporting member which would be covered by a fairing of plastic foam shaped to conform to the configuration of a human forearm.

While certain preferred embodiments of the invention have been specifically disclosed, it is understood that the invention is not limited thereto, as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims.

I claim:

1. A weight bearing prosthetic device comprising an elongated columnar element adapted to bear weight and a cosmetic covering supported thereon, said cosmetic covering being shaped to conform to a human limb and comprising a plurality of layers of light weight plastic foam disposed upon said columnar element for substantially the entire length thereof.

2. A weight bearing prosthetic device comprising an elongated columnar element adapted to bear weight and a cosmetic covering supported thereon, said cosmetic covering being shaped to conform to a human limb and comprising a plurality of layers of light weight plastic foam disposed upon said columnar element for substantially the entire length thereof and a protective covering disposed on said assembled layers of plastic foam.

3. A weight bearing prosthetic device comprising an elongated element adapted to bear the weight of the wearer and a cosmetic covering supported thereon, said cosmetic covering comprising a plurality of individually shaped layers of light-weight plastic foam disposed upon said columnar element for substantially the entire length thereof, said individually shaped layers when in assembled relation on said columnar element providing a contour which conforms to a human limb.

4. A weight bearing prosthetic device comprising an elongated element adapted to bear the weight of the wearer and a cosmetic covering supported thereon, said cosmetic covering being shaped to conform to a human limb and comprising a plurality of individually shaped layers of light-weight plastic foam disposed upon said columnar element for substantially the entire length thereof and a protective covering disposed on said assembled layers of plastic foam, said protective covering including a hard skin, a layer of rubber thereover and a flexible transparent skin the interior surface of which is coated with flesh appearing paint.

5. A weight bearing prosthetic device comprising an elongated tubular element, formed of laminated plastic, adapted to bear weight and a cosmetic covering supported thereon, said cosmetic covering being shaped to conform to a human limb and comprising a plurality of layers of plastic in cellular formation disposed upon said columnar element for substantially the entire length thereof and a protective covering disposed on said assembled layers of plastic foam, said protective covering comprising an inner, hard skin and an outer, flexible skin coated with flesh appearing paint.

6. A weight bearing prosthetic device comprising an elongated cylinder formed of plastic material, one end of which is pivotally affixed at the knee of a wearer and the other of which is pivotally connected to an artificial foot, and a cosmetic covering supported thereon, said cosmetic covering comprising a plurality of layers of plastic foam mounted on said elongated cylinder and each individually shaped whereby when in assembled relation on said elongated cylinder the contour of the assembly conforms to a human shank.

7. A weight bearing prostheic device comprising an elongated cylinder formed of plastic material, one end of which is pivotally affixed at the knee of a wearer and the other of which is pivotally connected to an artificial foot, and a cosmetic covering supported thereon, said cosmetic covering comprising a plurality of layers of plastic foam mounted on said elongated cylinder and each individually shaped whereby when in assembled relation on said elongated cylinder the contour of the assembly conforms to a human shank, and means applied to said fairing to provide a protective covering for the absorption of shock energy.

8. An artificial leg jointed at the knee and the foot and including a shank portion extending from knee to foot, said shank portion comprising a central tubular member of a length adapted to the height of the wearer and being formed of a high strength plastic material, and a cosmetic covering simulating a human shank supported on said tubular member, said cosmetic covering comprising a plurality of layers of plastic in cellular formation disposed upon said tubular member for substantially the length thereof.

9. An artificial leg jointed at the knee and the foot and including a shank portion extending from knee to foot, said shank portion comprising a central tubular member of a length adapted to the height of the wearer and being formed of a high strength plastic material, and a cosmetic covering simulating a human shank supported on said tubular member, said cosmetic covering comprising a plurality of layers of plastic in cellular formation disposed upon said tubular member for substantially the length thereof, and a

protective covering disposed on said assembled layers for the absorption of shock energy.

10. An artificial leg jointed at the knee and the foot and including a shank portion extending from knee to foot, said shank portion comprising a central tubular member of a length adapted to the height of the wearer and being formed of a laminated material comprising layers of a high strength filler impregnated with a synthetic thermosetting resin, and a cosmetic covering simulating a human shank supported on said tubular member, said cosmetic covering comprising a plurality of layers of plastic in cellular formation disposed upon said tubular member for substantially the length thereof, and a protective covering disposed on said assembled layers for the absorption of shock energy.

11. An artificial leg jointed at the knee and the foot and including a shank portion extending from knee to foot, said shank portion comprising a central tubular member of a length adapted to the height of the wearer and being formed of a laminated material comprising layers of fibrous glass fabric impregnated with a synthetic thermosetting resin, and a cosmetic covering simulating a human shank supported on said tubular member, said cosmetic covering comprising a plurality of layers of plastic in cellular formation disposed upon said tubular member for substantially the length thereof, and a protective covering disposed on said assembled layers for the absorption of shock energy.

12. An artificial leg jointed at the knee and the foot and including a shank portion extending from knee to foot, said shank portion comprising a central tubular member of a length adapted to the height of the wearer and being formed of a laminated material comprising layers of fibrous glass fabric impregnated with a synthetic thermosetting resin, and a cosmetic covering simulating a human shank supported on said tubular member, said cosmetic covering comprising a plurality of layers of cellular cellulose acetate disposed upon said tubular member for substantially the length thereof, and a protective covering disposed on said assembled layers for the absorption of shock energy.

13. An artificial leg composed of a thigh, a foot, and a shank portion interconnecting said thigh and said foot, with said shank portion comprising an elongated tubular element formed of a laminated material comprising layers of a fibrous glass fabric impregnated with a synthetic thermosetting resin and a cosmetic covering supported by said tubular element, said cosmetic covering comprising a plurality of individually shaped layers of cellular cellulose acetate which when assembled on said tubular element provide a contour simulating a human shank, and a protective coating disposed upon said assembled layers, said protective coating comprising a hard skin adhered to the exterior surface of said layers, formed of a fibrous glass fabric impregnated with a thermosetting resin, and a flexible coating arranged over said hard skin.

14. An artificial leg composed of a thigh, a foot, and a shank portion interconnecting said thigh and said foot, with said shank portion comprising an elongated tubular element formed of a laminated material comprising layers of a fibrous glass fabric impregnated with a synthetic thermosetting resin and a cosmetic covering supported by said tubular element, said cosmetic covering comprising a plurality of individually shaped layers of cellular cellulose acetate which when assembled on said tubular element provide a contour simulating a human shank, and a protective coating disposed upon said assembled layers, said protective coating comprising a hard skin adhered to the exterior surface of said layers, formed of a fibrous glass fabric impregnated with a thermosetting resin, and a flexible transparent vinyl resin film arranged over said hard skin.

15. An artificial leg composed of a thigh, a foot, and a shank portion pivotally interconnected with said thigh and said foot, with said shank portion comprising an elongated tubular element formed of a laminated material comprising layers of a fibrous glass fabric impregnated with a synthetic thermosetting resin and a cosmetic covering supported by said tubular element, said cosmetic covering comprising a plurality of individually shaped layers of cellular cellulose acetate which when assembled on said tubular element provide a contour simulating a human shank, and a protective coating disposed upon said assembled layers, said protective coating comprising a hard skin adhered to the exterior surface of said layers, formed of a fibrous glass fabric impregnated with a thermosetting resin, a layer of sponge rubber and a flexible transparent vinyl resin film over said hard skin.

GLENN G. HAVENS.

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