

Jan. 23, 1968

KIYOSHI INOUE

3,365,522

MAGNETIC FORMING OF NONCONDUCTIVE MATERIALS

Original Filed Aug. 6, 1964

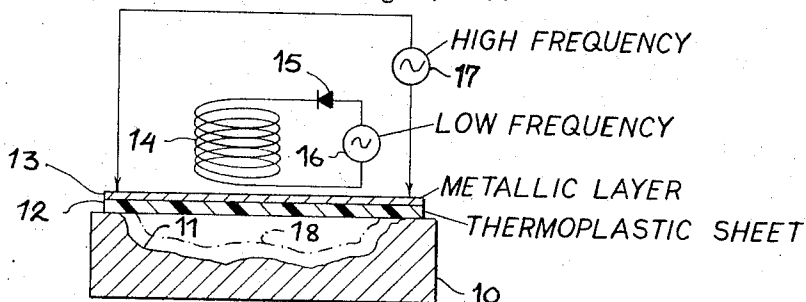


Fig. 1

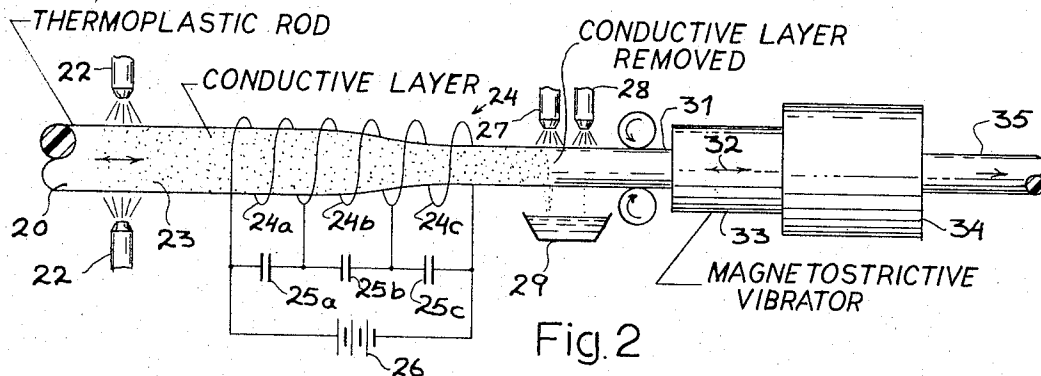


Fig. 2

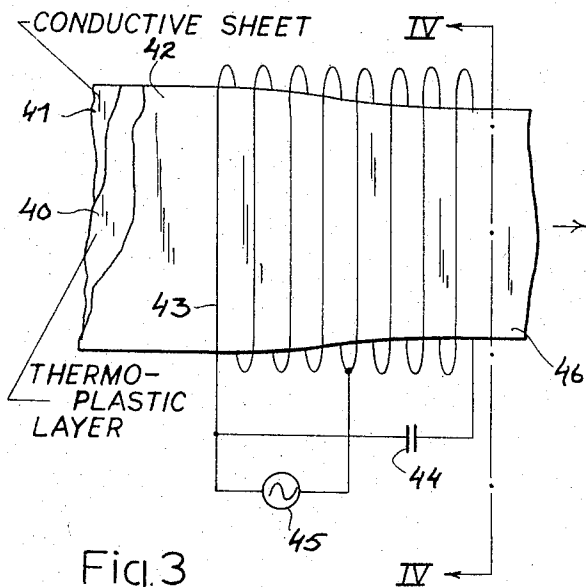


Fig. 3

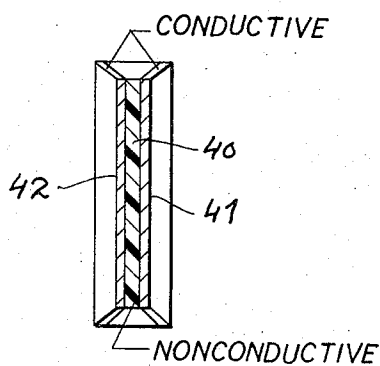


Fig. 4

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MAGNETIC FORMING OF NONCONDUCTIVE MATERIALS

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Continuation of application Ser. No. 300,356, Aug. 6, 1964, which is a continuation-in-part of application Ser. No. 273,480, Apr. 16, 1963. This application Mar. 28, 1967, Ser. No. 626,637

Claims priority, application Japan, Apr. 17, 1962, 37/15,761

6 Claims. (Cl. 264—25)

ABSTRACT OF THE DISCLOSURE

Method of continuously shaping plastic bodies by applying a electrically conductive, nonmagnetizable, layer to the body; generating eddy currents in the layer by magnetic force to heat and shape the article; thereafter removing the layer from the deformed plastic body.

My present invention relates to the magnetic shaping of bodies and, more particularly, to the forming and shaping of nonconductive materials capable of being rendered plastically deformable; this application is a continuation-in-part of my copending application Ser. No. 273,480, filed Apr. 16, 1963, now Patent No. 3,212,311 and a continuation of 300,356, now abandoned.

In the aforementioned copending application, I describe a method of and apparatus for the shaping of metal bodies without physical contact with a workpiece. Basically, this method involves the application to the conductive body of compressive electromagnetic force at least along plastically deformable regions of the body with the aid of a pulsed or variable magnetic field. Consequently, I was able to effect continuous drawing or static shaping of rod-shaped, tubular and sheetlike material, utilizing the principle that, when a strong magnetic flux is developed by the passage of an electric current through one or more coils surrounding the body, a magnetic induction force is developed which is capable of applying mechanical compression to the body surrounded by the coil. This principle is operative whether or not the body is itself ferromagnetic or contains ferromagnetic constituents since, as long as the body is conductive, an eddy current will be established in response to the variable magnetic field, this eddy current providing the necessary induction force when juxtaposed with the magnetic field of the coil. In this copending application, attention is directed to the fact that the inwardly directed compression forces can result in a continuous drawing of the body in a manner similar to conventional die-drawing techniques without, however, contact of a die with the body.

An important feature of that system is the provision of a plurality of axially offset coils which can be energized successfully by applying an axially shifting radial force to the body, thereby tending to draw it axially. Moreover, the axially offset coils may be connected in series or in parallel in a common energizing circuit and are, advantageously bridged by respective capacitive means for producing a traveling wave or a resonant network with the respective coils which simultaneously or successively discharge to provide the force pulses.

It is an object of the present invention to extend the principles set forth in the above-mentioned copending application to the shaping of nonmetallic and, indeed, even nonconductive materials.

It is another object of this invention to provide an improved method of shaping nonconductive thermoplastic bodies.

Still another object of this invention is to provide a

method of die forming nonconductive bodies without the use of high static pressures and the complex apparatus conventionally required.

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention, through a method of shaping electrically nonconductive bodies which involves the application to the body of an electrically conductive layer in which electrical currents can be induced by a magnetic field and the subsection of plastically deformable regions of this body to a magnetic field of an intensity sufficient to apply to the layer a force capable of deforming the plastically deformable portion of the body. The electrically conductive layer, which can be metallic or nonmetallic (e.g. graphite) can remain on the shaped body or can be removed therefrom by conventional techniques, in accordance with the present invention. It is, moreover, an important feature thereof that the magnetic field be applied generally transversely to the layer so that the nonconductive body may be juxtaposed with a die having contoured portions confronting the body whereby the mechanical force developed by the magnetic field deforms the body into a configuration substantially complementary to that of the die.

While, in many cases, the thermal energy produced by resistive dissipation of eddy currents in the conductive layer arising from the pulsed and variable magnetic field will suffice to heat the core of the conductive body, especially if the latter is a thin layer of a thermoplastic material, such as polyvinyl chloride. It is also possible, according to the invention, to pass an electric current through the conductive layer independently of the induced current in order to increase the heat supplied to the nonconductive body. The thermal energy can, of course, be a result of the voltage drop across the conductive layer which may be relatively thin so that it presents a substantial resistance to current flow. Any conventional method of applying the conductive layer to the nonconductive body may be employed. It is possible, for example, to laminate a foil of a conductive metal with the thermoplastic layer by thermal fusion, adhesive bonding, or merely by casting the resin onto the metallic surface. Alternatively, a metal- or graphite-containing paint can be brushed or sprayed onto the nonconductive body or the layer can be passed through a bath thereof. Furthermore, it is also possible to make use of metallic spray deposition, sputtering techniques, electrostatic coating and/or vacuum deposition for providing the conductive layer. If it is desirable to remove this layer, chemical methods (e.g. solvent or acid dissolution) or physical methods (e.g. evaporation) can be used.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a cross-sectional view schematically illustrating an apparatus for the die forming of thermoplastic resins;

FIG. 2 is a diagram of a system for the continuous drawing of nonconductive rods, according to the invention;

FIG. 3 is a plan view illustrating application of the present method to sheet material; and

FIG. 4 is a cross-sectional view taken along the lines IV—IV of FIG. 3.

In FIG. 1 of the drawing I show a die 10 whose contoured face is provided with a die cavity 11, confronting a nonconductive sheet 12 of thermoplastic material (e.g. polyvinyl chloride). The latter carries a laminated layer 13 of electrically conductive material; in this case the layer is bonded to the nonconductive sheet by an adhesive although conventional electroplating techniques (after

treatment with a conductive paint) and the others previously mentioned can be used. A coil 14, whose axis is perpendicular to the layer 13, is disposed so as to apply an axial magnetic field to the nonconductive body 12 and urge it into the die cavity 11 so that it occupies the position indicated at 18. Coil 14 is connected in series with a half-wave rectifier 15 and a low-frequency source 16 so that a pulsed unidirectional magnetic field is applied by coil 14 to the nonconductive body, each pulse progressively increasing and decreasing in intensity in accordance with each half cycle of a sine-wave. The conductive layer can have a thickness on the order of several microns (e.g. 10 microns) so that it possesses a high resistance and results in a development of a sufficiently high temperature, i.e. in the dissipation of eddy currents developed therein, to render the thermoplastic sheet (which can have a thickness of about 100 microns) plastically deformable when a magnetic field on the order of 10,000 Gauss is employed with a pulse duration of 30 microseconds. Temperatures on the order of 85° C. and sufficient to permit deformation of polyethylenes (low density), polymethyl methacrylates, polystyrenes and polyvinyl chlorides can be readily attained. If it is necessary, to supplement the heating effect of the magnetic field, a high-frequency alternating current source 17 (50 kilocycles/second) is bridged across the metal layer 13 to generate additional heat by resistive dissipation of electric energy; inductive and dielectric heating may also be used. The metal layer 13 may be stripped from the thermoplastic sheet or permitted to remain thereon as required.

In FIG. 2 I show a system for continuously drawing thermoplastic rod 20 so as to reduce its cross-section as that shown at 31. The rod can be coated at spray heads 22 with a metallic or graphitic layer 23 and is then passed through a succession of coils 24a-24c constituting an electromagnetic means 24 of the type described in my copending application. Each section 24a-24c of the electromagnetic means is bridged by a respective capacitor 26a-26c forming parallel resonant networks with the respective coil sections. A battery 26 is bridged across the entire coil and can apply a relatively high direct-current magnetic field (on the order of 10,000 Gauss) to the body processed. A take-up reel (not shown) is provided to draw the thermoplastic rod or filament 35 through the coil while a vibrator system 33, 34 longitudinally reciprocates the wire (arrow 32) at least at sonic frequencies, but preferably with supersonic frequencies on the order of kilocycles or megacycles. The vibrating device 34 can include a magnetostrictive yoke whose coils are connected in series aiding relationship across an alternating current source in parallel with a battery, as shown in my copending application mentioned above. The device further comprises a unidirectional chuck 33 which permits the filament 35 to be drawn through the vibrator. The chuck includes an axial spring (as illustrated in FIG. 8 of this copending application) which wedges balls against the wire to prevent return of the filament. The vibration of the body 20 induces a variable electromagnetic field in the resonant networks 24a, 25a etc. to provide the necessary compression. After the rod passes through the electromagnetic coil 24, a solvent for the conductive layer (e.g. an acid in the case of a metal) is sprayed onto the rod from a nozzle 27, the drippings being caught at 29. Another nozzle 28 rinses the rod. A suitable conductive layer can be nickel or copper and is removable with the aid of nitric acid.

In FIGS. 3 and 4 I show another arrangement wherein layers 41, 42 of a conductive material are deposited upon a thermoplastic sheet 40, the laminate being fed through a coil 43 which reduces its cross-section as best seen in FIG. 4 in the manner described above. Coil 43 is parametrically energized by an alternating current source 45 bridged across a portion thereof and a capacitor 44 con-

nected across the entire coil. This arrangement ensures that a pulsed electromagnetic field is applied to the body.

The invention described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the appended claims.

I claim:

1. A method of shaping an elongated electrically nonconductive and substantially nonmagnetic body, comprising the steps of:

continuously applying to said body an electrically conductive but nonmagnetizable layer capable of developing eddy currents therein;

continuously rendering said body plastically deformable at least along a portion thereof coated with said layer;

generating an eddy current in said layer at said portion of said body and repeatedly subjecting said body to a magnetic field generally transverse to said layer and interacting with the magnetic field of said eddy current to deform said portion of said body by the force developed by said magnetic fields; and thereafter continuously removing said layer from said body upon the deformation thereof by said force.

2. The method defined in claim 1 wherein the magnetic field to which said body is subjected is pulsed periodically.

3. The method defined in claim 1 wherein said body is rendered plastically deformable along said portion thereof at least in part by passing an electric heating current through said layer independently of the generation of said eddy current therein.

4. The method defined in claim 1 wherein said substantially nonmagnetizable and electrically nonconductive body is composed of a thermoplastic and said layer is composed of a nonferromagnetic metal.

5. A method of shaping a nonmagnetizable and electrically nonconductive thermoplastic sheet comprising the steps of:

applying to said thermoplastic sheet an electrically conductive layer;

placing said thermoplastic sheet upon a die with said sheet overlying a contoured surface thereof;

passing an electric current through said layer to render said thermoplastic sheet plastically deformable by resistive electric heating thereof;

applying a magnetic field transversely to said layer to deform the thermoplastic sheet juxtaposed with said contoured surface into a configuration complementary thereto; and

thereafter removing said layer.

6. The method defined in claim 1 wherein said substantially nonmagnetizable and electrically nonconductive body is composed of a thermoplastic and said layer is composed of graphite.

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