

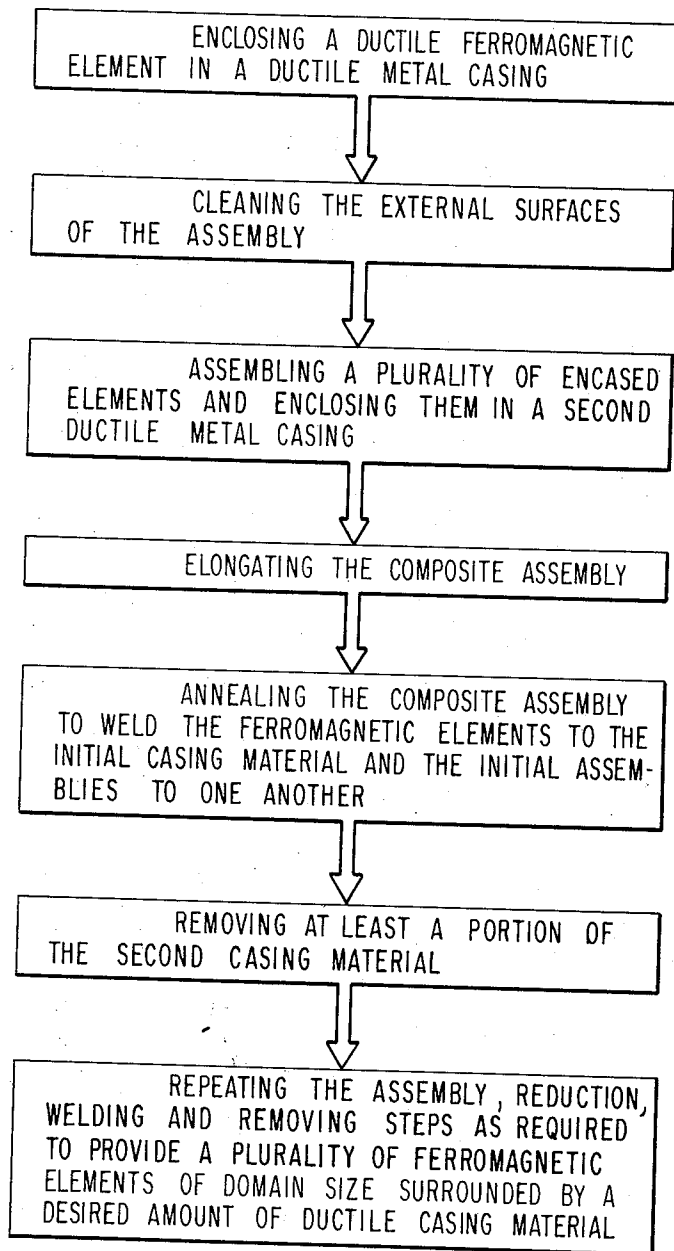
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METHOD OF PRODUCING HIGH ENERGY PERMANENT MAGNETS

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METHOD OF PRODUCING HIGH ENERGY PERMANENT MAGNETS

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Magnet materials with high coercive force obtained by reducing the cross-section of a composite body containing multi-domain ferromagnetic elements, suitably separated one from another, until the ferromagnetic elements become single-domain have been described in the specification of my Patent No. 3,029,496.

Whilst the general principles of the invention of Patent No. 3,029,496 can be used to manufacture permanent magnets with a substantial energy content, BH_{max} , permanent magnets having much higher energy contents are often required. The present invention has for its primary object to improve or modify the invention of Patent No. 3,029,496 so as to obtain permanent magnets having relatively high energy contents.

According to one method described and claimed in the specification of my Patent No. 3,029,496 a plurality of elongated multi-domain ductile ferromagnetic elements are each enclosed in a casing composed of a metal or metal alloy different to the material of the ferromagnetic elements but having the same ductility. The elements so enclosed are then each elongated until their cross-sectional areas are reduced as far as practicable. A plurality of the elongated encased ferromagnetic elements are then enclosed in a casing composed of a metal or metal alloy different to the material of the ferromagnetic elements to form a primary composite body; the primary composite body so formed is then elongated until its cross-sectional area is reduced as far as practicable. A plurality of elongated primary composite bodies are formed in a similar manner. A plurality of elongated primary composite bodies are then enclosed in a casing composed of a metal or metal alloy different to the material of the ferromagnetic elements to form a secondary composite body which is then elongated until its cross-sectional area is reduced as far as practicable. The series of steps are repeated as necessary until substantially all of the ferromagnetic elements are single domain. The casings enclosing the composite bodies are added primarily for the purpose of holding together the elements of each composite body during elongation.

The value of intrinsic coercive force H_c of the final magnet material depends principally upon the spacing of the ferromagnetic elements from each other, the spacing being controlled by the thickness of the casing enclosing each ferromagnetic element.

It has been ascertained that the greater the spacing between the ferromagnetic elements the greater is the intrinsic coercive force H_c of the final magnet material but the lower is the induction of the material, other factors remaining unaltered.

The value of intrinsic coercive force H_c of the final magnet material is nearly independent of the amount of material used in the casings to enclose the composite bodies. As against this, the introduction of the extra material when each composite body is enclosed in its casing lowers the value of magnetic induction B of the final magnet material and accordingly the value of magnetic energy BH_{max} of the final material.

If, as an example, the series includes five steps and each primary composite body has an initial diameter of 0.2 inch and is enclosed in a casing 0.01 inch thick and B_0

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is the induction of a primary composite body, the induction B_5 of the final magnet material will be about $.04B_0$.

Whilst a reduction in the number of steps will reduce the induction loss, this procedure increases the cost per pound of the material if it is carried out too far. In fact, since the starting size of each composite body is limited by practical considerations and the required total reduction of the diameter of the ferromagnetic elements is of the order of 10,000:1, the smaller the number of steps the finer is the required final size of each composite body. Irrespective of the method of reduction employed, the manufacture of composite bodies of very fine dimensions is more expensive, per pound weight, than that of large composite bodies.

According to the present invention, the above difficulties are eliminated or minimized by a modification of the method according to Patent No. 3,029,496 in which the metallic material for the casings to enclose the ductile ferromagnetic elements is so selected and the method is performed in a manner such that the casings containing the ferromagnetic elements are welded to each other during elongation of the composite body or bodies thereby to provide magnet materials having high energy content. The method is preferably performed so that the elements are cold welded to each other.

The advantages resulting from welding the encased elements together are: the thickness of the casings enclosing the composite bodies can be considerably reduced since the casing enclosing a composite body is subjected to lower stresses; it can be partially or totally removed before making the next composite body; breaks of individual elements within a composite body are less likely to occur.

Although reference has been made throughout to a casing enclosing each composite body, it should be appreciated that the casing may consist of a helically wound or longitudinally folded over tape.

The conditions for a satisfactory weld of the encased elements appear to be: clean surfaces, possibly roughened by wire brushing; sufficient cold work between anneals; and sufficiently high annealing temperatures. The last two conditions are fairly critically related to the requirements for achieving maximum energy content since if cold work between anneals and annealing temperatures exceed certain values, the final coercive force is lowered.

The conditions can be made less critical by enclosing the ferromagnetic element first with a casing composed of a material having properties more suitable for the retention of high coercive force and then with another outer casing having properties more suitable for welding.

The following is a preferred embodiment of the invention, the method steps of which are diagrammatically illustrated in the accompanying drawing.

The ferromagnetic elements are iron wires composed of commercial low carbon iron while the casings to enclose the iron wires are composed of 5% tin bronze (an alloy consisting of approximately 95% copper and 5% tin) or having about the same ductility as the iron wires. The wire is initially about 0.07 inch in diameter and the wall thickness of the casing is about 0.024 inch. The external surface of each encased wire is cleaned and the wires are then drawn to 0.0025 inch in diameter in a series of drawing operations with reductions in cross sectional area of approximately 12½% at each draw. Annealing is effected at 460° C. for 10 minutes at the stage when the cross sectional area is reduced to one quarter of that at the commencement of drawing and again as each cross sectional area is reduced to one quarter of that at the previous anneal.

About 1000 of the encased elements drawn to 0.0025 inch in diameter are then assembled together and enclosed in a casing composed of either 5% tin bronze with

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a wall thickness of 0.014 inch to form a primary composite body. The primary composite body is drawn to 0.003 inch in diameter with reductions in cross sectional area of approximately 12½% at each draw. Annealing is effected at 460° C. for 10 minutes at the stage when the cross sectional area is reduced to one twentieth of that at the commencement of drawing of the primary composite body and again as each cross sectional area is reduced to half that of the previous anneal.

A number of drawn primary composite bodies are formed in a similar manner.

The second casings enclosing the primary composite bodies are then partially or totally removed.

A secondary composite body consisting of about 800 of the uncased primary composite bodies drawn to 0.003 inch is then formed. The secondary composite body is drawn to 0.005 inch in diameter with reductions in cross sectional area of approximately 12½% taking place at each draw. Annealing is effected at 460° C. for 10 minutes at the stage when the cross sectional area is reduced to three tenths of that at the commencement of the drawing of the secondary composite body and again as each cross sectional area is reduced to half that at the previous anneal.

It has been ascertained that welding of the casings enclosing the elements to each other had taken place during drawing of the primary composite body between the first and second anneals.

The intrinsic coercive force of the secondary composite body when drawn to 0.005 inch in diameter is 330 oersteds in the hard drawn state and 420 oersteds after annealing.

When the ferromagnetic elements are enclosed first with a casing composed of a material having properties more suitable for the retention of high coercive force and then with another outer casing having properties more suitable for welding the casings may consist of 5% tin bronze.

The ferromagnetic elements and composite bodies may be so shaped in cross section as to further increase the energy value $BH_{\max}$.

I have found, in fact, that higher $BH_{\max}$ values are obtained in the final magnet material if the cross-sectional shape of the encased ferromagnetic elements is such as to leave little or no space between them when they are first enclosed in a casing to form a composite body i.e. if they are of regular polygonal shape in cross section. Suitable cross-sectional shapes are square or hexagonal. This effect is particularly noticeable when little or no extra encasing material is left around each element, a condition which is desirable for the achievement of high values of magnetic energy as above described.

The features above referred to may be combined, for example when spiral tape like wraps of the encasing material are placed around ferromagnetic elements of square shape, it is preferable to elongate the composite bodies by means of square rolling, instead of drawing, at least up to the stage where the elements are welded together.

Having now described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A method of producing permanent magnets having relatively high energy contents comprising the steps of providing a plurality of multi-domain rod-like ferromagnetic elements composed of a ductile material selected from the group consisting of ductile ferromagnetic metals and ductile ferromagnetic alloys of metals, enclosing each element in at least a first casing composed of a weldable material selected from the group consisting of metals and alloys of metals and different to the mate-

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rial selected for the ferromagnetic elements but having substantially the same ductility, cleaning the external surfaces of the encased ferromagnetic elements, enclosing a plurality of the encased ferromagnetic elements in a second casing composed of a material selected from the group consisting of metals and alloys of metals and different to the material selected for the ferromagnetic elements but having substantially the same ductility to form a primary composite body and having a first ratio of ferromagnetic material to weldable casing material higher than the desired ratio of the finished product, drawing the primary composite body by a series of drawing operations with annealing of the primary composite body between each drawing operation so that the first casings enclosing the ferromagnetic elements are welded to each other, removing at least a portion of the second casing from the composite body to yield a desired ratio of the second weldable casing material to the ratio of the ferromagnetic material elements, repeating the foregoing steps to form a plurality of said primary composite bodies, enclosing the plurality of said primary composite bodies in a third casing composed of a material selected from the group consisting of metals and alloys of metals and different to the material selected for the ferromagnetic elements but having substantially the same ductility to form a secondary composite body, drawing the secondary composite body by a series of drawing operations with annealing of the secondary composite body between each drawing operation so that the primary composite bodies are welded to each other, and repeating the foregoing steps as necessary with additional composite bodies until substantially all of the ferromagnetic elements are single domain thereby to provide a permanent magnet having high energy content and ferromagnetic material in the desired ratio to the weldable second casing material.

2. A method according to claim 1, wherein said first casing provided for each ferromagnetic element is composed of an inner casing of a material having properties suitable to produce a permanent magnetic material having high coercive force and an outer casing composed of a material suitable for welding.

3. A method according to claim 1, wherein said ferromagnetic elements are of regular polygonal shape in cross section.

4. A method according to claim 1, wherein said ferromagnetic elements are of regular polygonal shape in cross section, said first casing being formed from material of tape-like configuration which is spirally wrapped around the elements, and said series of drawing operations of the primary composite body being performed by square rolling at least up to a stage where the encased elements are welded together.

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