

Oct. 9, 1945.

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2,386,604

METHOD OF MOLDING UNDER PRESSURE METALLIC POWDERS

Filed Oct. 30, 1943

3 Sheets-Sheet 1

Fig. 1.

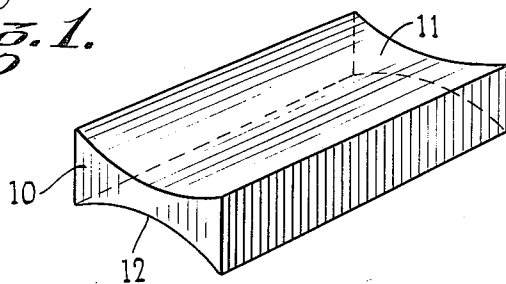
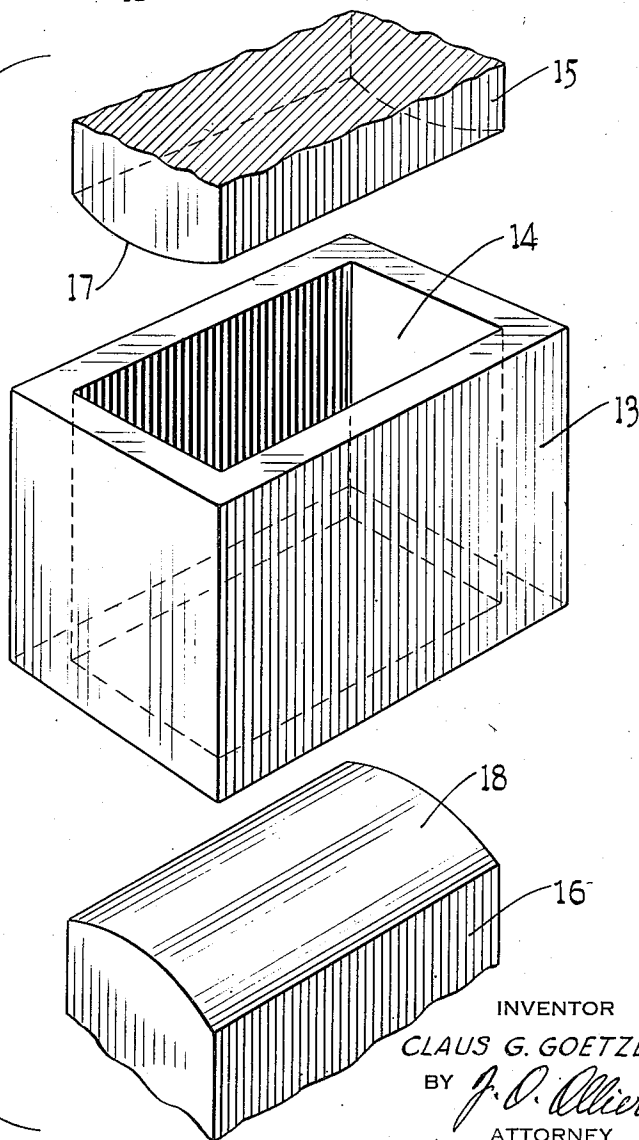


Fig. 2.



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3 Sheets-Sheet 2

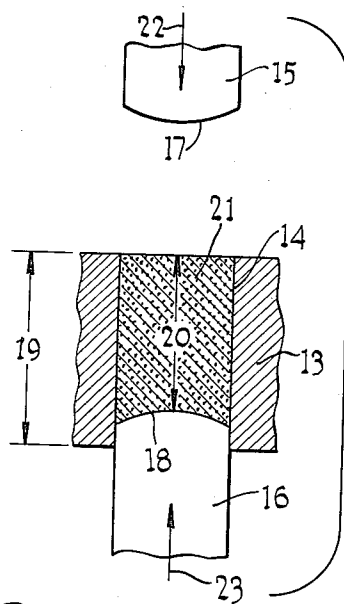


Fig. 3.

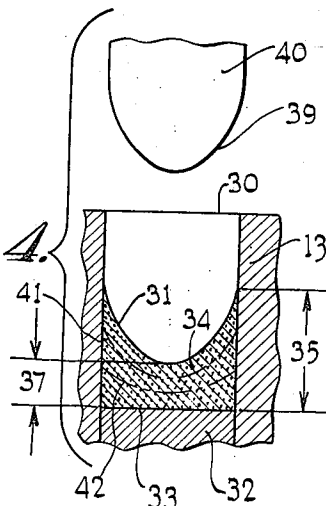


Fig. 4.

Fig. 3a.

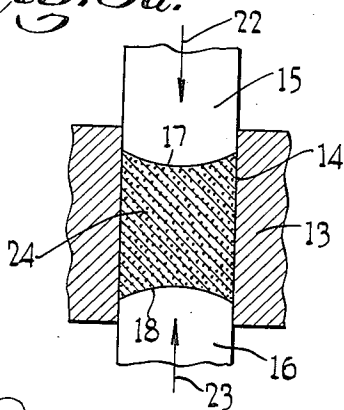


Fig. 5.

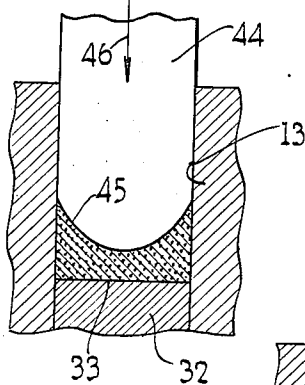


Fig. 3b.

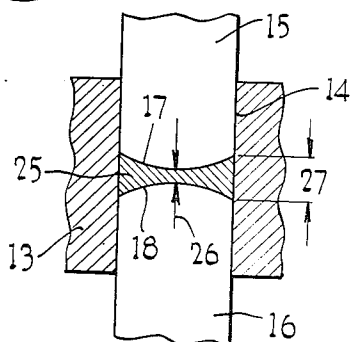
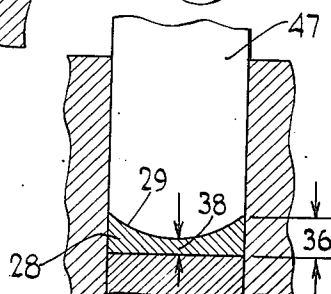


Fig. 6.



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3 Sheets-Sheet 3

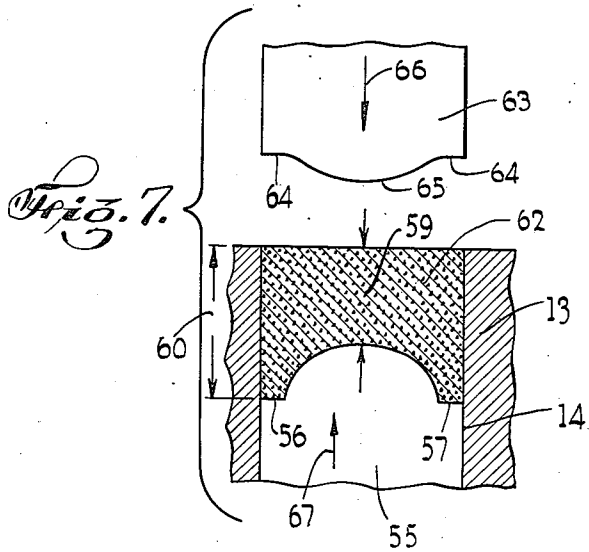


Fig. 8.

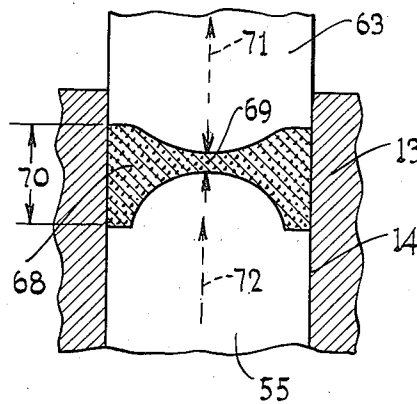
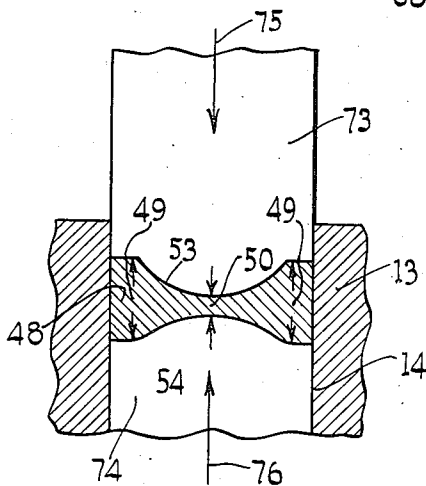


Fig. 9.



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2,386,604

METHOD OF MOLDING UNDER PRESSURE
METALLIC POWDERSClaus G. Goetzl, Yonkers, N. Y., assignor to
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Application October 30, 1943, Serial No. 508,308

9 Claims. (Cl. 75-22)

This invention relates to a method for compacting metallic powder of given apparent density into a coherent body of predetermined greater density and predetermined shape. The metallic powders may be comprised of one metal or metal composition, or a mixture of two or more metals or metal compositions, or one metal and one or more metal compositions. The coherent body of predetermined greater density may be porous or even completely or almost completely dense.

If the predetermined shape of the coherent body of predetermined greater density is a comparatively simple one, such as of a prism, cylinder or cone, compacting of the metallic powder of given apparent density to final shape generally does not meet with difficulties. However, if the shape of the coherent body and particularly the contour of a cross section through it essentially in the direction of pressing is rather complicated, considerable and often insurmountable difficulties are encountered in pressing. By a rather complicated configuration or contour of the coherent, compacted shape is understood one, the thickness of which, measured essentially in the direction of pressing, varies considerably so that upon compacting the powder fill according to the methods heretofore known, the concentrations of the metallic particles in the compact vary to such an extent that differences of mechanical strength and/or cracks result. In other words, such differences in thickness are considered considerable if they result in reduction or total lack of utility of the coherent body. In particular, shapes of a configuration including steps, considerably curved surfaces, flanges, or irregular projections, are considered rather complicated if those steps, etc. can be produced according to known methods of pressing only with disturbances of the particle concentration in the compact of the kind and effect as defined above.

In pressing any coherent shape from powdery initial material, it is customary to arrange for such conditions that the pressure is exerted primarily in the direction of the shortest extension or dimension of the shape to be compacted, in order to reduce to a minimum the average length of the paths over which the powder particles are displaced or moved during pressing: Then the least pressure is to be exerted in order to overcome the internal friction in the powder. If curved surfaces, etc. of the compacted shape are essentially parallel to the direction of pressing, generally no detrimental disturbances of the particle concentration manifested e. g. by friable or

brittle corners, edges etc., are observed. If, however, those steps, etc. are inclined and particularly perpendicular to the direction of pressure and relatively large or deep, detrimental disturbances of that concentration in the sense defined above, become unavoidable with known methods of pressing. It is obvious that no all-comprehensive data can be given as to when such curved surfaces, steps, etc., must result in detrimental disturbances of particle concentration; they can only be established in each individual case by experiment, viz. by designing a powder fill according to known methods, pressing it to shape, and examining its particle concentration or the effect of the latter. If there are e. g. no regions depleted of particles and consequent excessive porosity to be found, or the compacted shape proves to be of utility for the intended purpose, no change is to be made in the method of pressing. If, however, the disturbances result in draw-backs of the kind exemplified above, the known methods are unsatisfactory and the one according to the invention recommends itself.

If the apparent density of the metallic powder and the desired greater density of the compacted shape are given, the proportion of that greater density to that apparent density represents the compression ratio. Assuming that a copper powder of an apparent density of 2 is given and a dense compact of a greater density of 8 is to be pressed therefrom, the compression ratio amounts to 4:1. If, however, a rather porous shape of a greater density of 6.0 is to be compacted from the same powder, the compression ratio is only 3:1. If the powder of the apparent density 2.0 does not permit a compression ratio of 4:1 but only a ratio of 3:1, and a compact of the greater density of 8 is to be pressed, an initial powder of the apparent density 2.66 must be used. Usually the apparent density or loading weight of the powder of the same metal or metal composition increases with decreasing particle size. Other methods for increasing the apparent density of initial metallic powders are known and particularly described in Patent No. 2,306,665, Paul Schwarzkopf.

If there is a choice of initial powders of different apparent density of the same metallic material for pressing a shape of the same greater density therefrom, initial powders of greater apparent density are preferred because they permit reduction of the compression ratio and consequent use of quick acting presses and smaller strokes of their punches. With shapes of rather complicated configuration and resulting differences in thickness, however, the use of smaller compres-

sion ratios encountered difficulties in that particles in a part of the powder fill were to travel during compression over a longer distance in a direction parallel to that of pressure with little or no lateral deflection, while particles in another part of the fill were to travel over a shorter distance and also to be considerably deflected laterally. There is a certain limit of such lateral deflection for each powder, and therefore higher concentrations of particles result in parts of the compacted shape of little thickness (in the direction of pressing) compared with other parts of it of larger thickness. The latter are quasi depleted of particles, more porous and often friable, while the particles in parts of smaller thickness are highly concentrated, often severely overstrained and develop planes of rupture.

The behavior of the powder of given average particle size undergoing compression also depends on the softness and plasticity of its particles. The softer and more plastic the particles are, the easier they give plastically and deform under pressure and slip relative to or bypass one another. The softer and more plastic the powder particles are, the easier they are deflected laterally to the direction of pressing and shift and move from regions of high concentration developed during pressing to regions as yet of lower concentration, thereby tending to equalize the density of the shape.

There is therefore for each particular powder a certain optimum of effective pressure, the pressure being the smaller the better the plastic flow of the powder, i. e. the smaller its average particle size is and the better the plastic deformability and slip characteristics of the majority of its particles are. Under otherwise equal conditions, the required pressure is the larger, the larger the compression ratio is.

There are other factors determining particularly the maximum pressure. This pressure should be produced in an economical way and therefore not exceed certain limits, such as about 50 to 100 tons per square inch. The air trapped between the powder particles is also to be considered. As to the powder particles themselves, overstraining even of soft and plastic particles which may occur within a pressure range of about 100 to 150 tons per square inch, should be avoided.

In order to increase the plastic flow of any given powder and thereby reduce the pressure, lubricants can be admixed to the powder before it is filled into the die cavity. Mostly organic lubricants, such as paraffin, wax, stearite dissolved in acetone, are used and admixed in an amount of about $\frac{1}{2}$ to 3% by weight of the powder, which volatilise or evaporate at elevated temperatures of a few hundred degrees centigrade. Sometimes only the working surfaces of the die cavity and punches are covered by a lubricant in order to reduce abrasion during pressing and facilitate ejection.

It will be understood that in pressing shapes of rather complicated configuration, some or all of the factors stated above are to be considered. It is therefore an object of the invention to press metallic powder of chosen, i. e. given apparent density to a coherent body of predetermined shape and predetermined greater density, the thicknesses of which vary considerably in the direction of pressing, in such a manner that detrimental disturbances of the particle concentration in the compacted shape are avoided.

It is a further object of the invention to press metallic powder of chosen, i. e. given apparent density to a coherent body of predetermined

greater overall density and provided with one or more curved surfaces normal, or steps, recesses, off-sets, etc., somewhat inclined or essentially parallel to the direction of pressing, in such a manner that detrimental disturbances of the particle concentration in the compacted shape are avoided or, from another aspect, differences in particle concentration are kept within predetermined and tolerable limits.

It is still a further object of the invention to reduce wear of presses and dies used for producing coherent bodies of predetermined over-all density and rather complicated shape in which overstraining of particles and production of friable parts are avoided which, particularly upon further mechanical and/or thermal treatment, might result in undesired or detrimental variations of strength and/or hardness of the final body.

It is still another object of the invention to provide a method of pressing to final shape and predetermined greater over-all density, a metallic powder of chosen, i. e. given apparent density, filled in a die and levelled flush with the top of the die, and to impart to the final shape considerably different thicknesses measured essentially in the direction of pressing which, with pressing methods heretofore known, would cause detrimental disturbances of the particle concentration.

According to the invention, the metallic powder of chosen, i. e. given apparent density is compacted in a first pressing step to an intermediary coherent shape, the over-all density of which is smaller than the predetermined one of the final shape but larger than the apparent density of the powder, and the thicknesses of which, measured essentially in the direction of pressing, still exceed those of the final shape but are smaller than the corresponding ones of the powder fill comprised of the metallic powder. This intermediary shape is conveniently compacted in a die in which one or more punches act from one or opposite sides. The intermediary, coherent body is heat treated in a subsequent step and preferably outside the die at temperatures which increase the coherence and fix the particles of the intermediary shape without, however, resulting in its high sinter and densification to an extent which could render difficult or even prevent subsequent final shaping under pressure. The thus heat treated intermediary body is subjected thereafter to one or more mechanical shaping processes under pressure which give the body the final density and shape of rather complicated configuration.

The nature of the invention will be more clearly understood when the specification proceeds with reference to the drawings, in which Fig. 1 shows in a perspective view a rather simple body provided with curved surfaces essentially perpendicular to the direction of pressing, Fig. 2 in a similar view and schematically the working members of a press heretofore used for pressing to shape a body as illustrated in Fig. 1, Figs. 3, 3a and 3b in vertical cross section through a press as illustrated in Fig. 2, the progress and effect of compacting a powder fill, Figs. 4, 5 and 6 in vertical cross sections and rather schematically an approach to pressing the powder in an "ideal" manner, Fig. 7 in vertical cross section and schematically a press as used according to the invention in the first shaping step and at its start, Fig. 8 in a similar manner the same press at the end of the first shaping step and the intermediary shape obtained thereby, and Fig. 9 in a similar manner a press as used by the invention in a

shaping step subsequent to heat treating the intermediary shape and with its members in their final position.

Referring to Fig. 1, there is illustrated a final body 10 of rectangular horizontal cross section and curved surfaces 11, 12. The dimensions of the horizontal cross section considerably exceed the thicknesses or heights of the body between its surfaces 11, 12; consequently pressing the body from a powder fill in a direction of its shortest extensions and therefore essentially perpendicular to the surfaces 11, 12 recommends itself in order to reduce to a minimum the lengths of the paths over which the powder particles are to travel during compacting.

According to methods heretofore known, a die 13, Fig. 2, would be used for compacting which is provided with a cavity 14 of a horizontal cross section (perpendicular to the direction of pressing) essentially the same as the horizontal cross section of body 10. Assuming a double-action press, two punches 15, 16 are used of a horizontal cross section closely fitting die cavity 14 and exhibiting pressing surfaces 17, 18 curved in exactly the same way as the surfaces 11, 12 eventually to be produced on body 10.

The effect of the press illustrated in Fig. 2 upon a powder fill is shown in Figs. 3, 3a and 3b. The height 19 of die 13, Fig. 3, exceeds the height 20 of the powder fill 21 in die cavity 14 so as to provide in it sufficient guidance for the lower punch 16 which is set to form a bottom of cavity 14. Thereby cavity 14 can be used as a measuring receptacle for the metallic powder, e. g. of iron or copper, which is filled into this die cavity to its top and levelled. Punch 15 is then lowered in the direction of arrow 22 upon the powder fill 21 and enters die cavity 14 whereupon punch 16 is moved upwardly in the direction of arrow 23.

Fig. 3a shows the punches 15, 16 in an intermediary position during their pressing movement, having compressed between their surfaces 17 and 18 the initial powder fill 21 to the size 24. Fig. 3b shows the punches 15 and 16 in their final position within die cavity 14 and the initial powder fill 21 compacted to the final shape 25 equalling that of body 10, Fig. 1. As to be seen from Fig. 3b, the lateral thicknesses 27 of final shape 25 amounts to more than twice its center thickness 26. A comparison of Figs. 1 and 3b further shows that the center thickness 20, measured in the direction of pressing, of powder fill 21 was reduced to the thickness 26 in the compression ratio of almost 9:1 while the lateral thicknesses of powder fill 21 were reduced to the final thicknesses 27 in a compression ratio of less than 4:1 only. Due to these utterly different compression ratios the particle concentration in the center of compact 25 by far exceeds that in its lateral portions because even the most plastic and finest metal powder is incapable of being deflected laterally to an extent so as to equalize the particle concentration. Consequently the thin center area of shape 25 is dense and comprises severely strained particles while the larger lateral portions are rather porous and depleted of particles, giving cause to crumbling during ejection and further handling.

In order to avoid such detrimental disturbances in particle concentration, the compression ratio over the entire horizontal cross section of the powder fill under-going compression, should be essentially the same while compressing proceeds. In order to obtain such a result, a method should be used as illustrated with reference to Figs. 4 to 6 where it is assumed for simplicity's sake that

the finally compacted shape 28 exhibits a plane bottom surface and one curved upper surface 29 only.

A powder fill to be compressed at constant compression ratio cannot end flush with the top 30 of die cavity 13, Fig. 4, but should be shaped according to curve 31; this could be accomplished by setting punch 32 provided with a plane horizontal pressing surface 33 and cautiously piling the powder fill 34 upon it in such a manner that the curved surface 31 results. Assuming that a compression ratio 3:1 is appropriate for the powder chosen, the lateral heights 35 of powder fill 34, Fig. 4, are thrice the height 36 of the final compact 28, Fig. 6; the central height 37 of powder fill 34, Fig. 4 is thrice the central height 38 of compact 28, Fig. 6; and the intermediary heights of fill 34 are thrice those of the final compact 28.

In order to compress the thus shaped fill 34 at a constant compression ratio of 3:1, it is obvious that the pressing surface 39 of a punch 40 curved to fit surface 31, Fig. 4, should change its shape constantly and be flattened to the intermediary shape 41 and ultimately to the final shape 42, Fig. 4, which is the same as of surface 29, Fig. 6. Since this is practically impossible, one proceeds advantageously and according to the invention in using a punch 44, Fig. 5, provided with a pressing surface 45 curved according to the intermediary shape 41, Fig. 4, to compress fill 34 in the direction of arrow 46 until its center thickness corresponds to the center distance of surface 41 from the bottom surface 33, then withdraws punch 40 and replaces it by another punch 47, Fig. 6, the pressing surface 29 of which corresponds to the final shape 42, Fig. 4, and presses it downwardly to the position shown in Fig. 6 where the powder is compacted to the final shape 28.

Among the difficulties encountered in this process, is that of shaping the initial powder fill in the manner shown in Fig. 4 and having the compacted powder retain respectively the shapes 31 and 41 until the first punch is lowered upon it and while the punches 44 and 47 are exchanged.

The invention therefore proposes to proceed in the way illustrated in Figs. 7 to 9. There it is assumed that a final coherent compact of predetermined density 48, Fig. 9, is to be pressed from a powder which permits the use of a compression ratio 4:1, such as of pure sponge iron powder having an apparent density of 1.85 grams/cubic centimeter which is to be compressed into a final compact having a greater density of 7.4 or about 95%. Compacts of this density are of utility for all practical purposes in which soft iron is used, such as for electro-magnets.

Final compact 48, Fig. 9, is assumed to be of rectangular horizontal cross section and provided with lateral heavier portions of the thickness 49, curved surfaces 53, 54 essentially perpendicular to the direction of pressing 75, 76 and a thinner central portion of thickness 50; these thicknesses appear essentially parallel to the direction of pressing and differ so considerably that detrimental disturbances of particle concentrations would result if the shape were to be compacted in a method as described hereinbefore with reference to Fig. 2.

According to the invention, a die 13 having a cavity 14 is used, Fig. 7, which has a rectangular horizontal cross section, essentially perpendicular to the direction of pressing, the same as of the final shape 48, Fig. 9. A punch 55 is set in die cavity 14, Fig. 7, to form its bottom, and is

provided with an upper pressing surface which is horizontal on the sides 56, 57 and, rather sharply curved upwardly in between at 58. A powder fill 62 of the apparent density stated is filled in the cavity and levelled flush with its top. Center height 59 of the fill, Fig. 7, is four times the center height 50 of the final compact, Fig. 9, while the lateral height 60 of the fill is about twice the lateral height 49 of the final shape 48. Cavity 14 with punch 55 set therein serves as a "volumetric" measuring receptacle for the powder fill and makes possible fast filling and leveling out of the powder in the cavity by means of industrial press and molding equipment. The shape of the initial powder fill 62 can further be compared with a turned about "ideal" one, as explained with reference to Fig. 4, the "ideally" within practical limits—curved surface being provided by the supporting surfaces 56, 57, 58 of punch 55.

The upper punch 63 is provided with a pressing surface comprised of lateral horizontal portions 64 and a slightly downwardly curved center portion 65.

Punch 63 is lowered upon the powder fill 62, and thereafter both punches are moved in opposite direction (arrows 66, 67) toward one another until they arrive in the position shown in Fig. 8, where the initial powder fill 62 is compressed to the intermediary shape 68. It will be observed that its center thickness 69 still exceeds the center thickness 50 of the final compact 48 but is considerably smaller than the center thickness 59 of the initial powder fill 62, and that the lateral thicknesses 70 of intermediary shape 68 are considerably smaller than the lateral thicknesses 60 of powder fill 62 but still larger than the lateral thicknesses 49 of the final compact 48.

Thus compact 68 is densified to an extent that the particles due to increased surface contacts, interlocking, etc. adhere to one another and detrimental disturbances of particle concentration are avoided due to the low pressure required for attaining this intermediary compression ratio which permits deflections and lateral movements of the particles.

Now punch 63 is removed from and above cavity 14 in the direction of dotted arrow 71 and punch 55 further raised in the direction of dotted arrow 72, so that the compact 68 is lifted above the top of die 13 and can be removed manually or by suitable automatically actuated implements.

Shape 68 is now introduced into a heating chamber, such as a push furnace, in which it is heated at a temperature at which its particles are fritted or welded together without, however, being plasticised to such an extent that considerable shrinkage and densification occurs. Preferably a neutral or protective atmosphere, such as of desiccated hydrogen, is applied during heating. Suitable temperatures can easily be established for each powder or powdery mixture by a few experiments. Since sintering of a powder compact which is mechanically compressed as far as possible, starts at about 30% below the melting point of the powder or mixture, and high sintering temperatures are reached at about 15% to 10% below the melting point, temperatures suitable for the purposes of this invention will be found within the range of about 35% to about 20% below the melting point of the respective powder or mixture. Even if somewhat higher temperatures are used, it should be considered that the compact 68 undergoing this heat treat-

ment is not compacted to the fullest possible extent; its lateral heavier portions have been compacted only at a compression ratio of about 2:1 and its thinnest center portion at a compression ratio of about 3:1, while the powder could be compressed at a larger ratio and consequently higher pressure until the limit of mechanical compression is reached. Hence compact 68 is quite porous, approximately half way between the apparent density of the powder fill 62 and the ultimate greatest over-all density to be obtained. The contact areas between the particles have been increased and they also are plastically deformed to some extent. However, in order to fully sinter a body of such porosity, high sintering temperatures within the higher range stated hereinbefore are to be applied for a long period of time until it is completely densified. Therefore, if shape 68 is heat treated at a temperature within the approximate lower range stated and for a relatively short period of time only, such as about 10 to 30 minutes, some fritting or welding of its particles will be accomplished without densifying it to an extent which renders subsequent further shaping under pressure difficult or causes considerable shrinkage.

The coherence of the shape 68 being thus increased, it is now subjected to at least one further shaping process under pressure.

A subsequent shaping step is illustrated in Fig. 9 and a die 13 is used having a cavity 14 of the same horizontal cross-section as in the first compacting step; it was assumed in this exemplification of the invention that the final body 48 should have the same horizontal cross-section as the powder fill 62 in the first compacting step.

Again a double-action press is used in which punches 73, 74 act in opposite directions 75, 76. The pressing surface of lower punch 74 is shaped so as to impart the desired ultimate configuration to body 48. From a comparison of Figs. 7 and 9 it will be seen that the center portion of the pressing surface 54 of lower punch 74 is curved to a lesser extent than the corresponding pressing surface 58 of punch 55. Punch 74 is set in die cavity 14 so as to form its bottom, and body 68 placed in the cavity upon surface 54. Thereafter the upper punch 73 is lowered into cavity 14; its pressing surface 53 differs from that of punch 63, and a comparison of Figs. 7 and 9 shows that the center portion of pressing surface 53 of punch 73 is curved more sharply than the corresponding portion of pressing surface 65 of punch 63; furthermore, the lateral portions of pressing surface 53 continue into the center portion with quite a sharp edge.

While the pressure with which punches 63, 55 have been moved toward one another in the first compacting step and compressed powder fill 62, amounted e. g. to about 5 tons per square inch (a spongy pure iron powder being assumed), and is in general between about 2 to about 10 tons per square inch (in exceptional cases, such as large shapes and/or harder powder or mixture up to about 15 tons per square inch), the pressure ultimately exerted by the punches 73, 74 will amount to about 40 to 50 tons per square inch (for a pure spongy iron powder) and generally to about 25 to about 60 tons per square inch and more (within commercial limits), as the case may be. Hence in the end position of punches 73, 74 shown in Fig. 9, intermediary shape 68 is compacted to final shape 48 and its over-all density is increased to the desired greater final one.

From the above it will be appreciated that the invention proceeds from a powder fill of given apparent density or volume, and of a shape best suited for being compacted into an intermediary shape which in turn is best suited for being pressed to final shape. The shape of the powder fill is related to the intermediary shape, and the latter to the final shape in such a manner that in each pressing step the powder particles travel over the shortest possible paths and their lateral deflections from the direction of pressing are reduced to a minimum.

The powder subjected to the first compacting step is compressed to relatively low density so that small pressures suffice for deforming it, at which the powder flows plastically easy, i. e. its particles slip relative to each other and can be displaced and deflected laterally to the direction of pressing, whereby different powder concentrations in adjacent regions of the powdery mass undergoing compression are equalised. Therefore, in the exemplification of Figs. 7, 8 the powder concentration in the center portion which is thinnest will not differ considerably from that in the lateral, heavy and thicker portions, although the compression ratio of the center portion is considerably larger than that of the lateral portions.

In order to shape the powder fill in a manner approaching the "ideal" one, the pressing surface of the punch forming the bottom of the die cavity is shaped, particularly curved, rather different from the final shape, while the pressing surface of the upper punch working upon the levelled top surface of the powder fill more closely resembles the final shape.

The coherence of the intermediary shape permits ejection and handling but not compacting under increasingly heavy pressures in a subsequent and final shaping step; the mechanically coherent and porous intermediary shape 68 would almost immediately crack and crumble when the punches shown in Fig. 9 act upon it, whereby the equal particle distribution within that shape were lost. By fixing and reinforcing the relative position of the particles in the intermediary shape and thereby its shear resistance by the interposed heat treatment proposed by the invention, such destruction of the intermediary shape is prevented and it will give and be deformed by further shaping under pressure in the cold, and the particle concentration preserved.

The cold deformability of the thus heat treated intermediary shape is also aided by its porosity retained during heat treatment. As a general rule, the average porosity of the mechanically compressed intermediate body should be within the range of about 20% above and below the halfway value between the apparent density of the fill and the desired greater overall density of the final body. This porosity should be retained substantially during heat treatment, and will, as a general rule, not be reduced by more than 5 to 10% though somewhat higher reduction will not be detrimental.

During deformation by compression of the intermediary to the final shape, the compression ratios of portions of different thicknesses do not differ sufficiently to cause detrimental disturbances of particle concentration.

The ratio of the shaping or compacting pressures before and after heat treatment depends upon the type of powder used and the configuration and size of the final shape. As a general rule, the final second pressure will exceed the

first pressure in a ratio from about 3:1 to about 10:1.

If a volatile lubricant of the kind and amount stated hereinbefore, is admixed to the initial powder, it will be removed completely during the interposed heat treatment according to the invention.

While a preferred mode of performing the invention has been described above and a double-action press illustrated, it should be understood that a single-action press can be used to advantage whenever relatively simple shapes, though of complicated configuration, are to be made. In such event the die cavity can be provided with a bottom forming an integral part of the die, or a floating bottom can be used.

In the event that bodies of very complicated shape are to be made, the powder fill can be pre-shaped and compacted to the intermediary shape according to the method and with a press as described in my copending application Ser. No. 500,788. If the transformation of the intermediary, heat treated shape to the final shape is difficult for similar reasons, the method and press as described in my above mentioned copending application can be used in a subsequent and/or final shaping step.

The final shaping or coining step or steps may impart interior stresses to the shape and in such event, the shape may be subjected to subsequent thermal treatment, particularly annealing.

In practice a body as shown in Fig. 1 and representing a field pole piece, has been pressed from powdery pure spongy iron, passing a 300 mesh sieve. It was approximately 2" long, 1½" wide, its largest thickness was ¾" and its smallest thickness about ⅓". The powder was admixed with about 1% a lubricant of a zinc-stearite base and treated in a die and with two sets of punches as illustrated in Figs. 7, 8, and 9, respectively. The volume of the intermediary porous shape was about halfway between that of the powder fill and the final shape, and its porosity of the order of 50%. The pressure used in the first compacting step was in the order of 5 tons per square inch. The intermediary shape was treated at a temperature of about 1100° C. for about 15 to 20 minutes and all volatile impurities, including oxygen and foreign matter introduced by the lubricant, were thereby removed simultaneously; variations of temperature between about 1050° C. and about 1200° C. were possible. The so heat treated intermediary body was then coined to final shape under a pressure of the order of 50 tons per square inch. Its final overall or average density appeared to be about 93%, was within the limit or tolerance required, and did not vary more than 5% throughout a cross section. Considering the great variations in relatively small thicknesses, this result is considered outstanding compared with everything attainable heretofore with known commercial processes. It could be further improved by subsequent annealing at a temperature between about 600° to 720° C.

The invention is not limited to any of the exemplifications and illustrations hereinbefore described but to be derived in its broadest aspects from the appended claims, and is capable of many variations within that scope. Thus, for instance, the fractional molding according to the invention, comprising two characteristic subsequent pressing steps at increased pressures and a "fixing" heat treatment interposed between them, can be carried out in three or even more characteristic

pressing steps with a "fixing" heat treatment interposed between each pair of them, and the effective final pressure in the second and subsequent characteristic step being higher than in a preceding one.

What I claim is:

1. In a method of pressing from metallic powder of given apparent density a coherent body of predetermined greater overall and minimum density and shape, the thicknesses of which, measured essentially in the direction of pressing, differ considerably so that compressing in one step is apt to cause detrimental variations of particle concentration, the steps of compacting said powder to an intermediary coherent shape of an overall density approximating, within about 20%, a density halfway between said apparent and greater ones, heating said intermediary shape at a temperature about 35 to 20% below the melting temperature of said powder and for a period of about 10 to 30 minutes so as to increase the coherence of said intermediary shape without essentially increasing its density, and thereafter imparting to said intermediary shape the predetermined one by at least one further compacting step at considerably higher pressure than used in the preceding compacting step.

2. In a method of pressing from metallic powder of given apparent density a coherent final body of greater over-all density and final shape the thicknesses of which, measured essentially in the direction of pressing, differ considerably so that compression in one step is apt to cause detrimental variations of particle concentration in the final body, the steps of forming from said powder a fill of a die cavity, of a smallest initial thickness exceeding the smallest final one substantially in the ratio of said greater to said apparent density, compressing said fill to an intermediary coherent shape the thicknesses of which are between said initial and final thicknesses and the over-all density of which approximates, within about 20%, a density half-way between said apparent and final greater density, subjecting said intermediary shape to heat treatment at elevated temperature and for a period of time so as to increase the coherence of said intermediary body in the solid state without essential densification, and thereafter subjecting said intermediary body to at least one further shaping operation under pressure considerably exceeding that used in the first compression step so as to increase its overall density to said final greater one, reduce its thicknesses to said final ones and impart to it said final shape.

3. In a method of pressing from metallic powder of given apparent density a coherent final body of greater overall density and final shape the thicknesses of which, measured essentially in the direction of pressing, differ considerably so that compression in one step is apt to cause detrimental variations of particle concentration in the final body, the steps of forming from said powder a fill of a die cavity of a smallest initial thickness exceeding the smallest final one substantially in the ratio of said greater to said apparent density, compressing essentially at room temperature said fill to an intermediary coherent body the thicknesses and overall density of which are respectively approximately half-way between said initial and final thicknesses and between said apparent and greater density, heat treating said intermediary body within low sintering temperature range so as to increase its coherence without

essential densification, and thereafter subjecting said body to at least one shaping operation essentially at room temperature under a pressure considerably exceeding that of the preceding compression so as to increase the overall density of said body to said final greater one, reduce its thicknesses to said final ones and impart to it said final shape.

4. In a method of pressing from iron powder, particularly spongy pure iron powder, of given apparent density a final body of predetermined greater overall density and shape, the thicknesses of which, measured essentially in the direction of pressing, differ considerably, the steps of compacting said powder at a pressure of about 2 to 10 tons per square inch at room temperature to an intermediary coherent shape of a density approximating, within about 20%, the density half-way between said apparent and greater overall densities, heat treating said intermediary shape between about 1050° C. and about 1200° C. for a time period of about 10 to 30 minutes so as to increase the coherence of said shape without essential densification, and thereafter imparting said final shape to said intermediary one by at least one pressing step at room temperature, applying a pressure between about 25 to about 60 tons per square inch.

5. In a process of molding a shape of smaller predetermined volume and consequent larger density from metallic powder of larger volume corresponding to its given apparent density, which process includes a first pressing step resulting in a coherent shape of a volume approximately half-way between said larger and predetermined volumes and a subsequent second pressing step at higher pressure than applied in the first step and resulting in said predetermined volume and density: the step of fixing the relative position of the powder particles in said coherent shape by heat treatment within low sintering temperature range for a time period short enough to avoid essential densification of said shape.

6. In a method as set forth in claim 2, forming a fill of a die cavity of a cross section measured perpendicularly to the direction of pressing, substantially equalling the largest cross section of the final shape.

7. In a method as set forth in claim 3, forming a fill of a die cavity of a cross section measured perpendicularly to the direction of pressing, substantially equalling the largest cross section of the final shape.

8. In a method as set forth in claim 4, compacting said powder to an intermediary coherent shape of a largest cross section measured perpendicularly to the direction of pressing, equalling that of the final body.

9. In a method of pressing from iron powder, particularly spongy pure iron powder, of given apparent density a final body of greater overall density and shape the thicknesses of which, measured essentially in the direction of pressing, differ considerably so that compression in one step would result in detrimental variations of particle concentration in the final body, the steps of forming from said powder a fill of a die cavity ending level with the top of the cavity and of a smallest initial thickness exceeding the corresponding one of the final shape substantially in the ratio of said greater to said apparent density, and compacting said fill to final shape and greater overall density in two successive cold pressing steps, the first completed at a pressure resulting

in a coherent compact of an overall density approximately halfway between said apparent and greater final one and in a maximum compression ratio still permitting plastic powder flow, while the second step is completed at considerably greater pressure than the first one and results in the final shape of greater over-all density, and

heating the compact resulting from the first pressing to low sintering temperature for a time period sufficient to fix the powder particles in their place and increase the shear resistance and cold deformability of the compact without increasing essentially its density.

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