

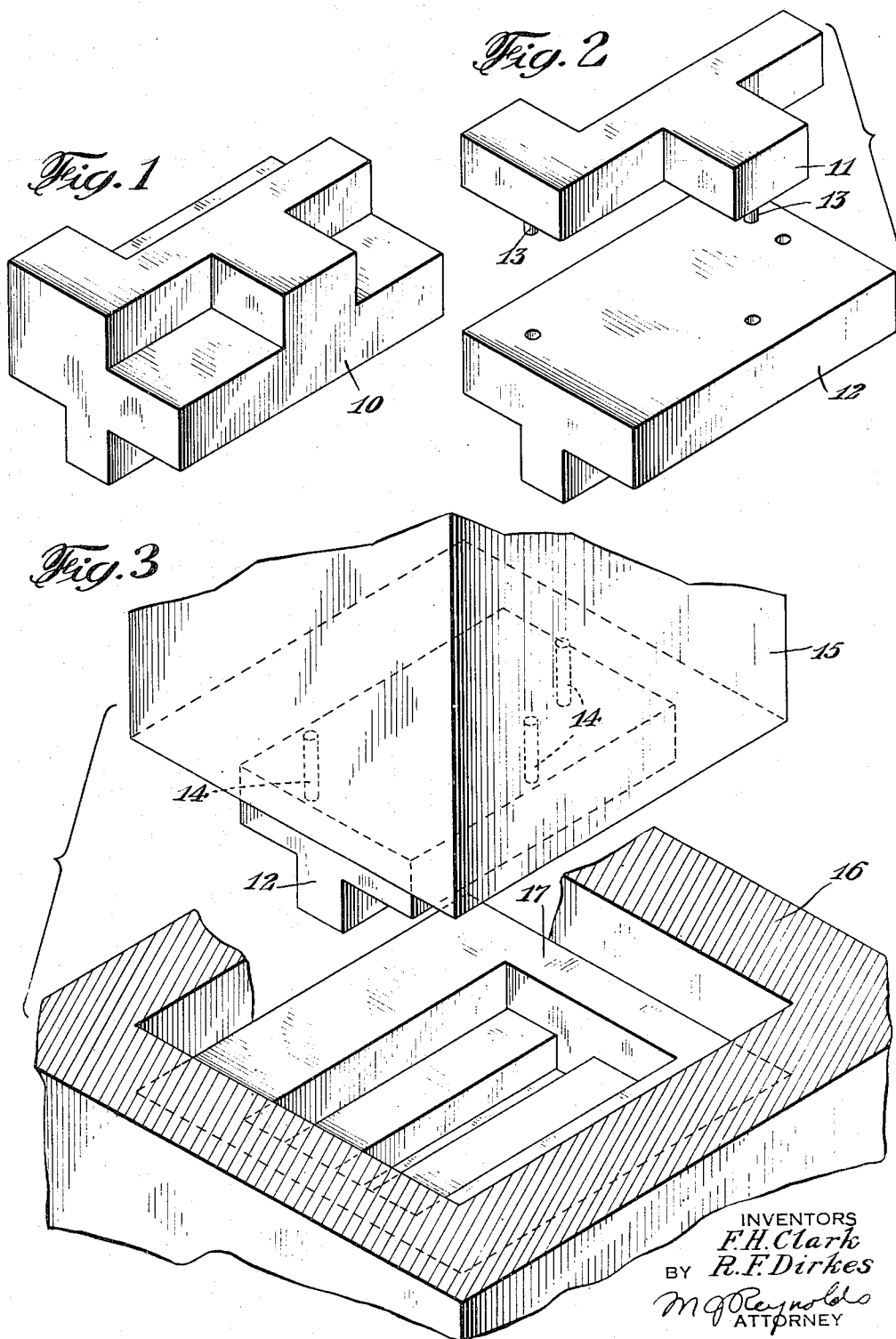
March 10, 1942.

F. H. CLARK ET AL
METALLURGY OF FERROUS METALS

2,275,420

Filed April 30, 1938

4 Sheets-Sheet 1



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Fig. 4

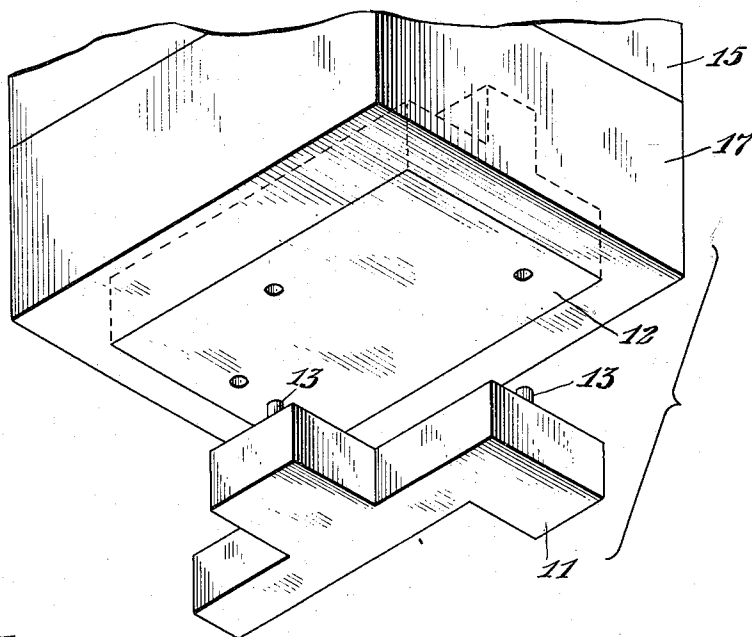
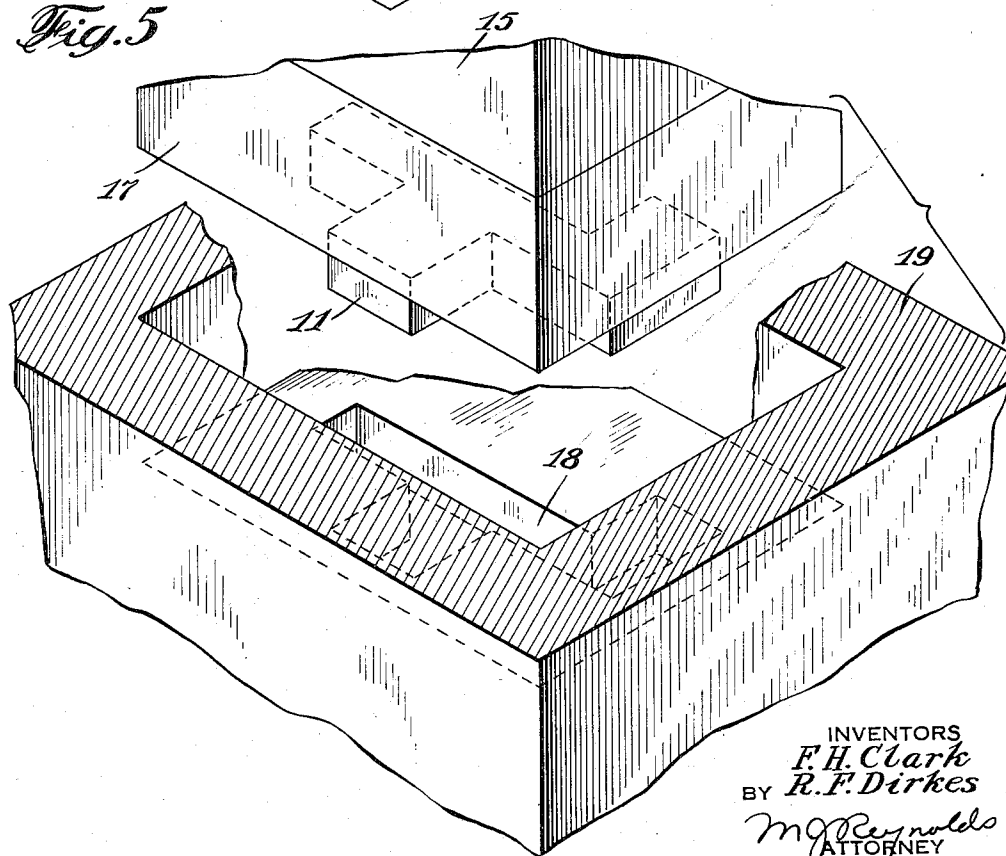


Fig. 5



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Fig. 6

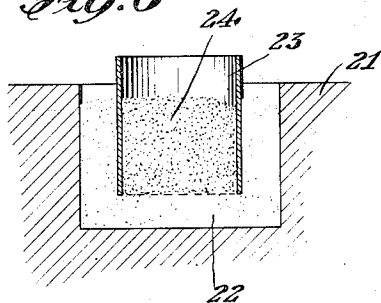


Fig. 8

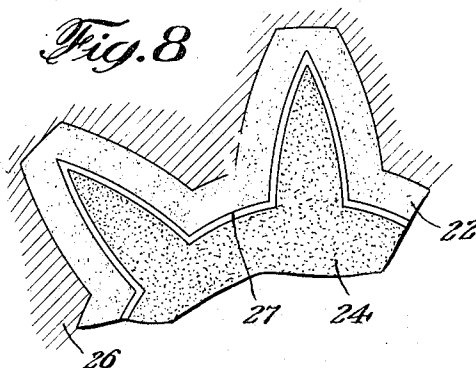


Fig. 7

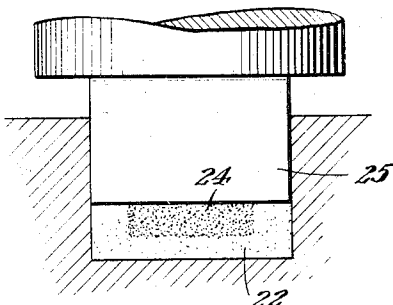


Fig. 9

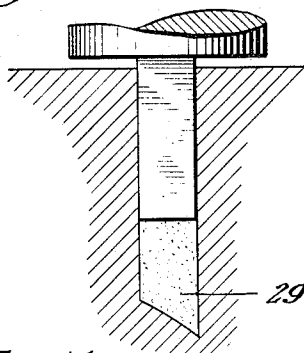


Fig. 10

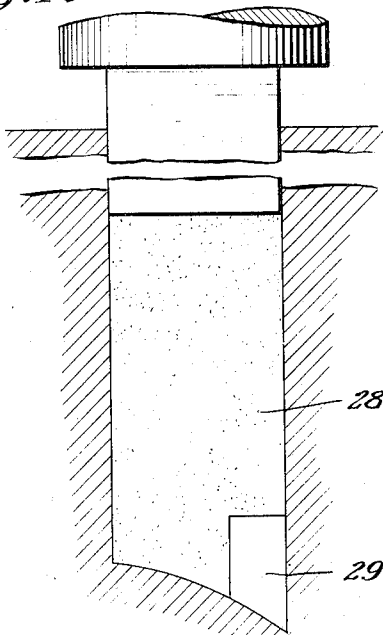
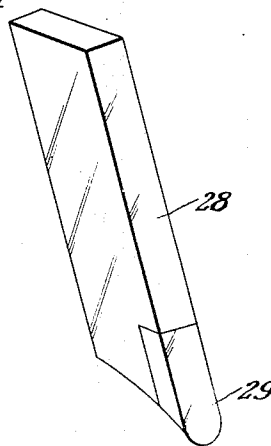


Fig. 11



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Fig. 12



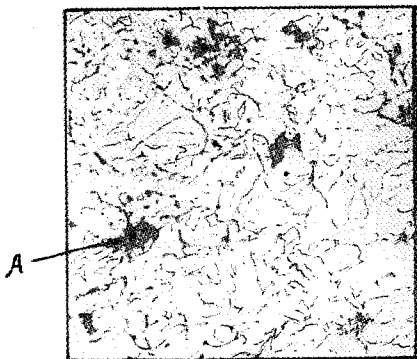
PEARLITE STRUCTURE OF
ANNEALED STEEL PRODUCED
FROM SINTERED POWDERS

Fig. 13



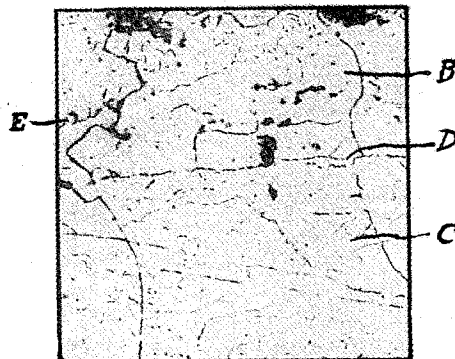
MARTENSITE STRUCTURE OF
HARDENED STEEL PRODUCED
FROM SINTERED POWDERS

Fig. 14



SINTERED MIXTURE OF
IRON POWDER AND CARBON

Fig. 15



SINTERED IRON POWDER BONDED
TO COLD ROLLED STEEL

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2,275,420

METALLURGY OF FERROUS METALS

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Application April 30, 1938, Serial No. 205,392

4 Claims. (Cl. 75-22)

This invention relates to the fabrication of hardened or hardenable ferrous metal bodies from metal powders and particularly to the forming of such metals in predetermined shapes, as in the making of dies, gears, cams, tools, etc.

At the present time articles, such as tools, dies, etc., composed of hardened steel have been rather expensive and it has been difficult to shape accurately such parts in the desired forms, particularly where the forms are complicated, since hardenable steels are difficult to work by mechanical tools and during such working there is a tendency of the materials to crack, tear, etc. Moreover, it is extremely difficult to obtain identical duplicates by such methods.

It has been proposed heretofore to fabricate metallic products from pressed and sintered powders. Such procedure, however, has not been possible in the production of steel since the commercially available iron powder consists of nearly pure iron and therefore when pressed and sintered the resulting bodies are soft. They may be hardened by carburizing in accordance with known processes, but such carburization requires long and troublesome heating and results only in a relatively thin case or layer of hardened material. The core, however, is of practically pure iron and hence is soft and has little strength as compared with acceptable carburizing steels. Moreover, the penetration of the carbon is not uniform and therefore the thickness of the case is irregular, particularly on articles of complicated shape. Because of the extreme thinness of the hardened portion of the article, and the irregular thickness thereof, extreme care is required in grinding the parts to finished size. This carburization, moreover, destroys the surface smoothness of the parts.

One of the objects of the present invention is to provide a process of producing hardened steel articles in which the disadvantages in the prior methods will be eliminated and more even and uniform hardness obtained.

Another object is to obtain homogeneity in the structure of the parts.

A further object is to eliminate or reduce the amount of mechanical working required on the parts.

A still further object is to provide a method of producing duplicate parts which are substantially identical.

A further object is to provide an improved method of making accurately inter-fitting die members.

A further object is to facilitate the production

of hardened steel parts such as dies, gears, cams, etc.

Another object is to produce hardened steel parts made from pressed metal powders.

5 Another object is to provide a method of fabricating composite metal parts having hardened wear-resisting portions and softer shock resisting parts.

10 Other objects and advantages of the invention will hereinafter appear.

Efforts have been made heretofore to provide a steel by pressing and sintering mixtures of ferrous powders and carbon. Such methods have been unsuccessful, however, since at elevated temperatures, carbon in the solid state does not readily diffuse into iron, in the absence of oxygen. Such parts cannot be heated directly in oxygen since the oxygen produces very heavy oxidation and scaling of the parts and consequently it is necessary to use a reducing gas such as carbon monoxide. This is expensive, however, and results only in a surface or case hardening of the parts since carbon monoxide does not penetrate to any substantial depth into the compressed material. We have found, however, that when carbon is once combined with the iron in the form of iron carbide, the carbon is mobile at elevated temperatures, when mixed with pure iron powder. By mixing iron powder and iron carbide powder and pressing the mixture in a die at high pressure, we are able to attain very close mechanical contact of the two constituents. If this compact is then heated above the critical range where the microstructure is austenitic, the carbon in the combined form readily diffuses through the iron powder and a steel results which has the carbon distributed in a uniform or zero concentration gradient, i. e., the microstructure is the same throughout the whole piece. This alloy, on cooling, has a pearlite structure and can be treated like an ordinary steel. It can be reheated at normalizing temperatures to refine the grain and can then be reheated to the usual temperatures and quenched in water or oil to produce a hardened structure, like tool steel and tempered subsequently to relieve the hardening strains.

45 It is obvious that other elements for alloying the steel can be added to the iron powder and iron carbide mixture to produce the whole range of alloy steels as they are known commercially today. These include for example: nickel, chromium, manganese, vanadium, tungsten, etc., and even silicon, phosphorus and sulphur which are ordinarily considered as impurities in steels. The

carbon in the combined form of iron carbide may be added to the iron powder in the form of a powdered ferro alloy, high in combined carbon, such as ferro-chrome, ferro-nickel, ferro-silicon, etc. It is desirable, however, to remove the free carbon from such powdered ferro alloys, as, in the case of magnetic materials, by magnetic separation.

The percentage of iron carbide added to the powdered iron may be varied in accordance with the particular characteristics desired in the ultimate product and when ferro-alloys, such as mentioned above, are employed, the amount of such powders used depends on the percentage of iron carbide in such alloys. For the production of tool steels we prefer to add from about 5 to 20% iron carbide to pure iron powder but of course the amount is not critical and depends entirely upon the desired characteristics of the finished product. For example, we may mix iron powder in the portion of 84% to 16% of an iron carbide containing approximately 6.67% of combined carbon and press the powders into coherent form as set forth hereinafter to produce a carbon steel containing approximately 1% of carbon.

The iron powder and powdered carbide or carbide containing alloy may be mixed in the proper proportions in a ball or baffle mill, preferably the latter, since it results in a more general and intimate mixing without changing the shape or size of the individual metal or carbide particles. After intimate mixing thereof, the powders may be pressed into the desired shape by hydraulic or other forms of presses under a pressure of the magnitude of 100,000 lbs. per square inch. The pressed parts are then sintered in a non-oxidizing atmosphere at a temperature above the critical range of the metal, for a sufficient period to obtain a thorough diffusion of the carbide through the mass, whereby a homogeneous structure is obtained. The time of heating is dependent upon the size of the article, the percentage of carbide therein and the nature of the ferro-alloy employed and may vary from a few minutes to an hour or more. During this period the powdered particles coalesce and a fine, uniform and homogeneous structure is produced. After sintering, the parts may be quenched and hardened like ordinary steel or if it is desired to machine the parts they may be cooled slowly so as to produce the soft structure of annealed steel and after machining they may be reheated and hardened by quenching and then tempered in accordance with the practice employed in the ordinary metallurgy of carbon and alloy steels. If desired the entire article may be composed of hardened steel or it may be composite, that is, formed partly of hard steel and partly of mild steel, these composite metals being formed by using powders of different composition in different parts of the pressed article. The use of a mild steel core in parts such as gears, cams, etc. relieves the strains set up in the hardened outer shell.

In order that the invention may be more fully understood, reference will be had to the accompanying drawings wherein:

Fig. 1 is a perspective view of arbitrary form of a drop forging, selected by way of example, to explain one aspect of the present invention;

Fig. 2 is an exploded view of a two-part pattern used in producing dies, in accordance with the present invention, for the forging shown in Fig. 1;

Figs. 3, 4 and 5 are perspective views illustrating successive steps in producing such a die from the patterns of Fig. 2;

Fig. 6 is a fragmentary vertical sectional view of the mold of a press, showing a method of loading the same with powdered metals for the production of a composite metal body;

Fig. 7 is a similar view after the compressing of the powders in the mold of Fig. 6;

Fig. 8 is a fragmentary plan view of a mold for producing composite steel gears;

Figs. 9 and 10 illustrate steps in the production of a composite cutting tool;

Fig. 11 is a perspective view of the tool produced according to the process illustrated in Figs. 9 and 10;

Fig. 12 is a photo-micrograph, at 1000X, of a sample of steel before hardening, produced in accordance with the present invention;

Fig. 13 is a photo-micrograph, at 1000X, of a similar sample, after hardening;

Fig. 14 is a photo-micrograph, at 500X, of a sintered mixture of iron powder and free carbon; and

Fig. 15 is a photo-micrograph, at 500X, of the bond between a composite body produced by pressing ferrous powder in contact with a low carbon steel and sintering the resulting compact.

As heretofore stated one aspect of the present invention involves the production of dies from powdered metals for such operations as drop forging, coining, etc. from steels of varying carbon contents. As shown in Fig. 1, an article of irregular form has been selected for purpose of illustration to describe one method for producing dies from which such article may be easily and readily fabricated. By this means such dies, if desired, may be duplicated in exact replica.

For the purpose of producing such dies, it is first necessary to construct a pattern and in Fig. 2 such a pattern is shown as composed of two relatively simple parts 11 and 12, adapted to be secured together by means of dowels 13 or in any other accepted manner. Preferably the pattern is composed of easy workable metal such as brass or aluminum. The portion 11 of the pattern is used to form a die for one head of the forging hammer and the other portion 12 of the pattern is employed to produce the die for the other head of the forging hammer.

In producing one of the forging dies, the pattern member 12 is secured by dowels 14, as shown in Fig. 3, to the plunger 15 of a hydraulic or other form of press capable of producing pressures of the order of magnitude of 100,000 lbs. per square inch. Disposed from the anvil of the press is a container 16, preferably of a standard or stock size and shape, depending upon the size and shape of the die to be produced. This container is filled to a depth of approximately three times the depth of the pattern member with a mixture of desired metallic powders. In accordance with the present invention such mixture may consist of powdered iron and iron carbide either in the forms of pure iron carbide or as a ferro-alloy rich in iron carbide, such as ferro-chrome, etc. The plunger is thereafter forced into the container under the pressure, as stated, of approximately one hundred thousand pounds per square inch, which pressure compacts the powder to approximately one-third of its original bulk to form the die 17. The exact reduction in volume of the powder, upon compression, is dependent upon the particular mixture employed. After the pressing operation the compressed powders are

coherent and may be readily removed from the mold, by means of an ejector of the type commonly employed in presses of this type. The compact may then be sintered at a suitable temperature in an inert atmosphere, such as hydrogen, for a sufficient period to coalesce the constituents into a uniform mass. The sintering temperature should be above the critical range of the particular composition so that the carbide will be dissolved in the austenite, as in the ordinary heat treating process of steels. After sintering the die 17 may be quenched from the sintering temperature, in the accepted manner ordinary to steel treatment, but if it is desired to machine or lap the die, in cases where extreme accuracy is necessary, it may, after sintering, be cooled slowly to keep it in an annealed condition so that the microstructure will be sorbitic-pearlite. In this annealed condition it may be readily machined to approximately finished size. Thereupon it may be reheated to its critical temperature and hardened by quenching in water or oil and subsequently tempered. It will be necessary thereafter only to lap slightly to finished size.

The sintered, hardened and tempered die, 17, as shown in Fig. 4, is then secured to the plunger 15 of the press and the pattern member 12 placed in the recess which is formed in the die 17, the pattern being secured thereto in the accepted manner of using stick shellac or other adhesive. The second pattern member 11 is secured to the pattern member 12 by means of dowels so that it protrudes from the lower surface of the plunger face. Then the second die member 18 is formed in the same manner as the first die member by forcing the plunger 15 into a container 19 filled with the powdered metal so as to produce a recess therein corresponding to the pattern, as illustrated in Fig. 5. The second die member is removed from the press, sintered, hardened and tempered in the manner of the first die member. The pattern member is then removed from the first die member and both die members can be employed as the mating members of a drop forge or coining machine.

It will be obvious that with no machining of parts, after the production of the pattern, other than a slight lapping any number of identical dies may be constructed from the patterns. Thus the output of any desired number of drop forge hammers will be uniform and substantially indistinguishable.

While a typical forging die has been illustrated in Figs. 1 to 5, it is to be understood that other kinds of dies or tools may be produced by a corresponding process. For instance, in the case of mating die members, the male member may be first produced from a suitable pattern, by pressing, sintering and hardening a mixture of the iron and iron carbide powder and this member then secured to the plunger of the press and used to press the female member from the powdered mixture. In this way exact interfitting of the members are secured. In some cases a slight lapping of the die parts may be desirable, which may be done before the hardening operation.

In accordance with the foregoing description the dies have a homogeneous structure throughout, consisting of a hardened tool steel. However, if desired they may be composed of composite metals such as a shock resisting mild steel body with a layer of any desired thickness of hardened tool steel thereon. In Figs. 6 and 7

there is shown diagrammatically a method by which such a composite body may be produced. In Fig. 6 the container 21 is partially filled with a mixture 22 of iron powder and iron carbide and a cylinder 23 of desired cross-section is placed in the container, the space between such cylinder and the walls of the container being filled with the above mixture. The interior of the cylinder is then filled with pure iron powder 24 or a mixture lower in combined carbon, whereupon the cylinder 23 is removed and the plunger 25 actuates to compress the powders as shown in Fig. 7. The resulting compact is then removed from the container and sintered to the critical range of the particular mixture of the pure iron and iron carbide employed, during which the particles coalesce as before stated and form an outer steel jacket with a pure iron core. The mild steel core absorbs the strains set up in the outer jacket during the hardening process. In addition it acts as a shock absorbent for the die in operation, thereby prolonging the life of the dies. The soft steel body also permits holes for securing the die to the forge or punch to be drilled after the hardening process or to permit additional holes to be drilled to adapt the die to other forges.

This is a practical advantage of considerable importance in that fixtures of punches and forges vary in the position of the holding members so that under conditions now existing it is necessary to keep a hardened steel die allocated to a certain machine because of inability to modify the position of the mounting holes after the die is hardened.

It is not essential, however, that the mild steel core be formed from the compressed powder, but if desired a preformed core of the desired shape, size and composition may be utilized and the mixture of pure iron and iron carbide compressed around the same. It has been found in such cases that during the sintering, the mixture of powders forms a bond with the solid iron core to the same extent as it does with one formed of compressed powder.

In Fig. 8 is shown a method of producing gears having a mild steel center and a hardened steel outer layer. In this case the container 26 is shaped to conform to the outer contour of the gear and an inner cylinder 27 is spaced therefrom to permit the separation of the pure iron powder 24 or mixture lower in combined carbon from the mixture 22 of iron and iron carbide powders. After filling of the container with these powders the cylinder 27 is removed in the same manner as the cylinder 22 of Fig. 6 and the powders compressed sintered, hardened and tempered in the manner above described. It is to be understood, of course, that the central portion of the core may also be formed of a solid metal with the powders compressed about it.

Fig. 11 shows a cutting tool composed of a body 28 of shock-resisting steel and a point 29 of hardened steel. The method of making this is illustrated in Figs. 9 and 10, Fig. 9 showing the pressing of the steel point 29 and Fig. 10 the incorporation of such point with the mild steel support. The point 29 is composed of the desired mixture of iron and iron carbide powders and after being compacted it may be sintered if desired before being united to the mild steel backing or it may be united thereto previous to sintering. After compression, and either before or after sintering the point 29 is placed in a container, as shown in Fig. 10, and the space there-

above and around filled with pure iron powder or mixture lower in combined carbon, which is compressed about the point by means of the plunger in the usual manner. The composite body so formed is then sintered as described above to unite the point with the backing member.

Of course, if desired the transition from hardened to mild steel may be gradual, as by progressively decreasing the iron carbide content of the mixture as the mild steel portion is approached.

Fig. 12 is a photomicrograph taken at magnification of one thousand diameters of a sample of steel produced by pressing iron and iron carbide with a small amount of ferrochrome, at a pressure of about one hundred thousand pounds per square inch and sintering in a hydrogen atmosphere at a temperature of about 1500° F., which was above the critical range for the particular mixture employed. The sample was permitted to cool slowly and shows the typical pearlite structure of steel in the annealed state. This structure is uniform throughout the mass and corresponds in all respects to annealed steel as produced by melting and casting.

Fig. 13 shows the micro-structure, at one thousand diameters, of the steel produced in accordance with the above process after it has been hardened by heating above the critical range and quenching in accordance with the usual practice of treating steels. It shows the typical martensite structure of hardened steel.

As heretofore stated, it has not been found possible to produce these structures by adding solid carbon alone to the iron powder, since the carbon in a solid condition does not diffuse into the iron when treated in accordance with any of the methods heretofore available. In Fig. 14 is shown a photomicrograph taken at 500 diameters, of a sample produced by heating a compact of pure iron powder and free carbon under the same conditions as the sample shown in Fig. 12. It will be noted from this photomicrograph that the carbon is in the uncombined state as indicated by the lack of pearlite structure and by the large masses of free carbon, such as shown by the dark areas (A) throughout the photomicrograph.

Fig. 15 is a photomicrograph taken at a magnification of five hundred diameters to show the bond obtained between sintered powdered iron when compressed in contact with a piece of cold rolled steel. It will be noted that the bond between the sintered iron portion C and the cold rolled steel portion B is extremely intimate, with the crystal boundaries so oriented that they cross the original junction line D of the two parts. Attention is directed to grain marked E which shows how upon sintering of the mass, the grains of the original cold rolled steel portion B have been elongated and grown into the sintered portion C. Consequently the weld or juncture has a strength equal to that of any other portion of the body.

The term "iron carbide" as used in the specification and appended claims includes not only pure iron carbide but the various complex carbides which occur in ferro alloys, such as iron chromium carbide, iron vanadium carbide, etc., and mixtures thereof, or any material containing iron and combined carbon.

It is obvious, of course, that the process is susceptible to the formation of bodies of complicated and irregular shapes and for a variety of uses. Many changes may be made in the method of compacting the powders and uniting powders of different compositions, those shown being by way of illustration only. Therefore we do not desire to be limited to the specific processes and structures disclosed, but contemplate all variations thereof as coming within the scope of the appended claims.

What we claim is:

1. The method of making composite articles of hardenable steel and mild steel comprising compressing a mass of iron powder, containing combined carbon in sufficient amount to produce a mild steel upon sintering, in contact with a mass composed of iron powder containing a higher percentage of combined carbon, to render the same coherent, heating at a temperature above the critical range of steel of the composition of said latter mass and continuing the heating until the combined carbon in the latter mass is substantially uniformly diffused into said mass.

2. The method of making composite articles of hardenable steel and mild steel comprising compressing a mass composed of iron powder containing from 5 to 20% of iron carbide in contact with a mild steel body, at a pressure sufficient to render the powdered mass coherent and to cause adherence thereof to the mild steel body, heating to a sufficient temperature to cause coalescence of the powdered material and bonding thereof to the mild steel body and continuing said heating until said iron carbide is substantially uniformly diffused into said mass.

3. The method of making dies comprising pressing in the form of the die a mass of iron powder composed of a central portion containing sufficient combined carbon to produce a mild steel on sintering, and an outer portion containing sufficient combined carbon to produce a hardenable steel on sintering, heating said mass to above the critical range of the composition of said outer mass and continuing the heating until said combined carbon is substantially uniformly diffused into said outer mass.

4. The method of making dies comprising pressing, in the form of the die about a central core of mild steel, a mass of iron powder containing combined carbon in sufficient amount to produce a hardenable steel upon sintering, heating the same to above the critical range of the said mass and continuing said heating until the combined carbon is substantially uniformly diffused into said mass.

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