

Nov. 1, 1966

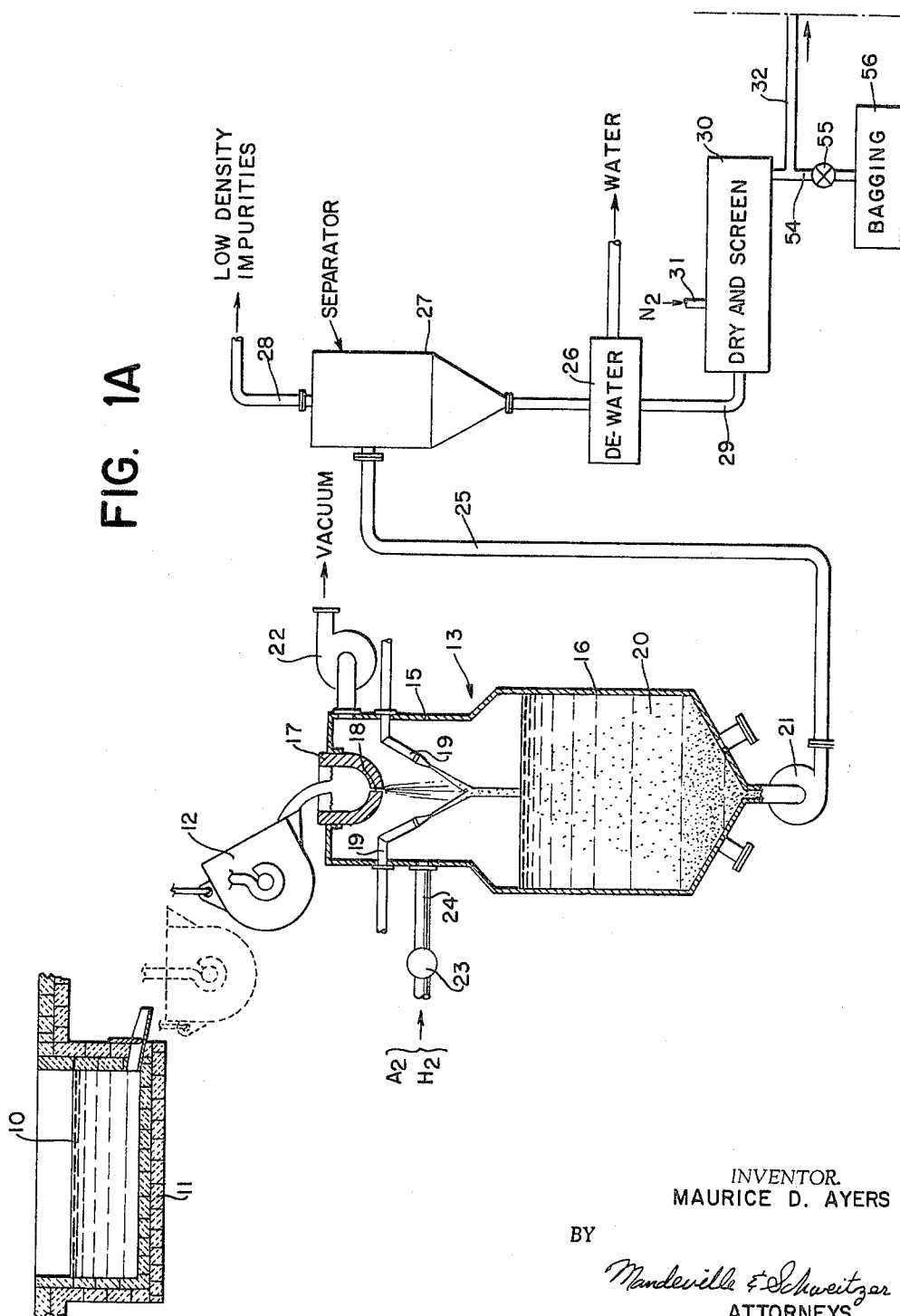
M. D. AYERS
CONTINUOUS PRODUCTION OF STRIP AND OTHER METAL
PRODUCTS FROM MOLTEN METAL

3,281,893

Filed Nov. 4, 1963

3 Sheets-Sheet 1

FIG. 1A



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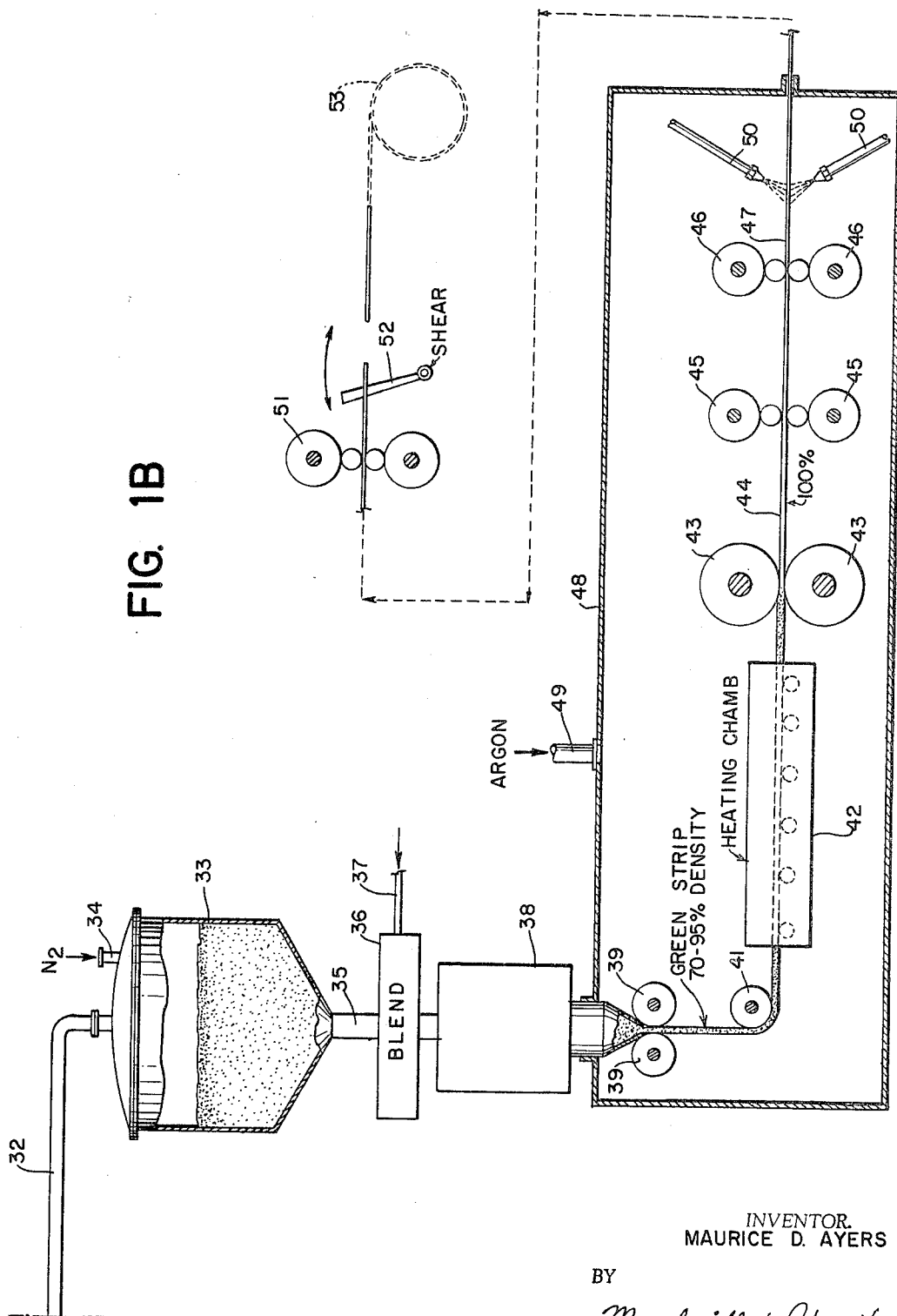
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3 Sheets-Sheet 2

FIG. 1B



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3 Sheets-Sheet 3

FIG. 2

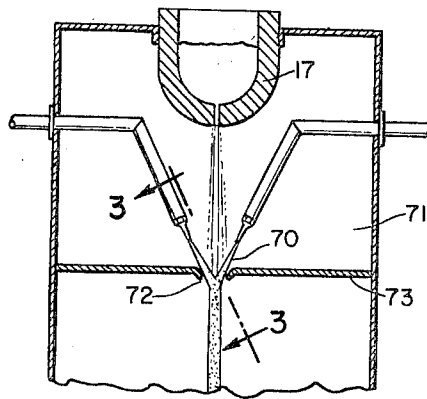


FIG. 3

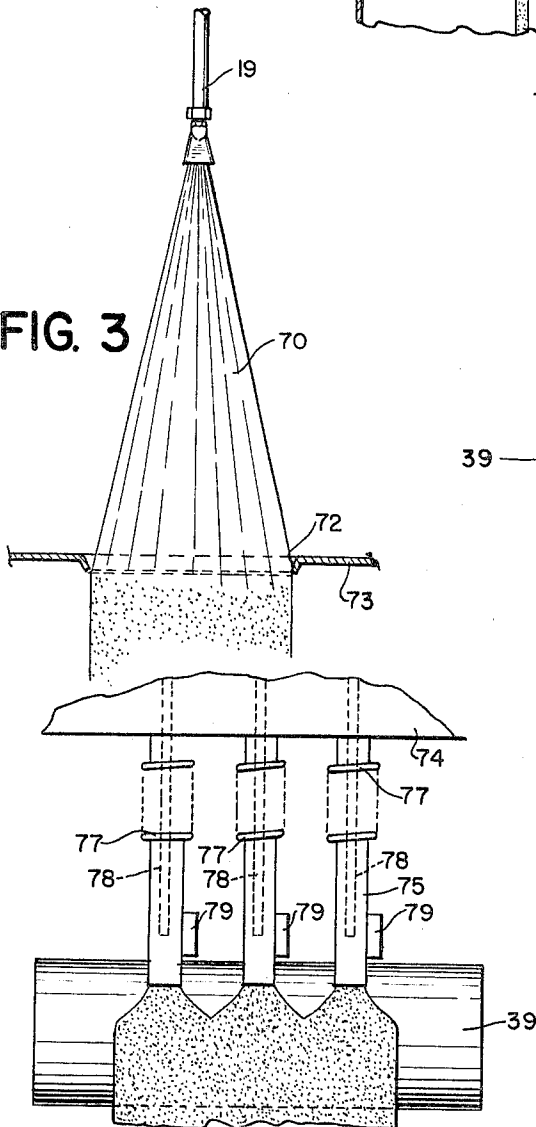


FIG. 4

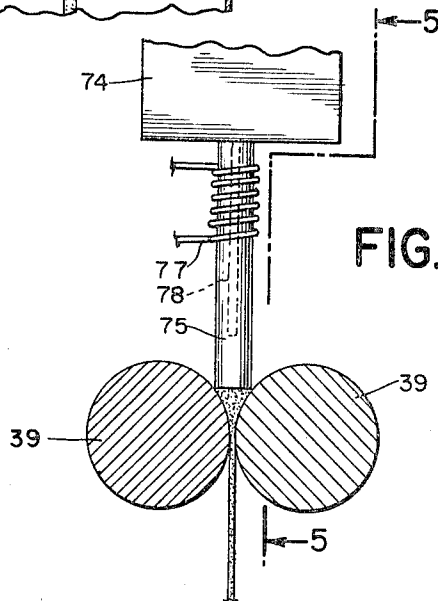


FIG. 5

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3,281,893

CONTINUOUS PRODUCTION OF STRIP AND OTHER METAL PRODUCTS FROM MOLTEN METAL

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Filed Nov. 4, 1963, Ser. No. 321,246

1 Claim. (Cl. 18—2.5)

The present invention relates to a method for the production of metal products, such as strip, bars, and rods, in a continuous procedure, commencing with the preparation of refined or controlled analysis molten metal and proceeding without interruption of process control to the stage of hot- or cold-rolled strip, for example, or other substantially finished metal forms suitable for delivery to metal users. The invention is also directed to certain novel and improved apparatuses and arrangements of equipment for carrying out the new process or parts thereof. Although the process and apparatus of the present invention are applicable to other metals, the invention is applicable to particular advantage in the continuous production from high purity molten metal of high purity and/or controlled analysis steel or iron products.

In the production of merchant products and other substantially finished forms of steel, it is conventional to cast the refined or controlled analysis molten metal into large ingots. These ingots are then transferred to large soaking pits where they are kept for a period of time and are brought to a uniformly high temperature. After a desired "soaking period" the heated ingots are transferred to a slabbing or blooming mill and rolled into slabs, blooms, or billets. These intermediate products often are then inventoried and subsequently reheated for hot rolling and sometimes also cold rolling into strip, bars, or rods, in a sequence of operations usually involving special heating cycles, pickling, annealing, and the like. The output of the secondary rolling procedures desirably is in a form suitable for delivery to the steel consumer.

In more recent developments having limited acceptance in the steel industry, the molten metal is continuously cast into slabs or billets, after degassing, which has an advantage of eliminating ingot pouring, soaking pits, and slabbing or blooming mills, but still involves all of the procedural steps and equipment of the merchant or finishing mill, for converting the slabs and billets into final end products.

In either the conventional processing or in the continuous casting system, each step of the overall process is of a character to require huge installations of plant and equipment and large capital investments. For example, economical installations for strip production typically must have a capacity of at least 300,000 tons annually (and usually upwards of 500,000 tons), and the capital and other requirements for such installations tend to limit participation in the industry to a relatively few well-financed companies at a relatively limited number of geographical locations.

In accordance with the present invention, significant economic and other advantages are realized through a novel process of converting molten metal directly into the form of strip, bars, or rods, in an effectively uninterrupted process involving an intermediate conversion of molten steel to iron powder and the subsequent conversion of the powdered iron or steel to the desired strip or other finished or semi-finished form. In following the new simplified process, significant economies are realized and substantial reductions in capital costs for equipment are made possible. Further, it is economically feasible to carry out the process of the invention with low cost, low capacity installations, so that an iron and steel making process may be carried out at a greater number of

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locations in closer proximity to individual cities or plants to which the output is to be delivered or in proximity to sources of raw materials. In this connection, the process of the invention may be economically carried out with plants of 5,000 to 100,000 ton capacity.

Additional important economic advantages are realized because of significantly higher yields in converting molten metal to finished products, yields of 90 percent and above being contemplated with the process of the invention, as compared to yields in the range of 70 percent for many conventional production procedures. Further, with the simplified process of the invention, it is possible to produce hot-rolled strip gauges which are well below the conventional hot-rolled gauges, to supply substantial markets presently filled only by substantially more expensive cold reduced strip.

In addition to the above-stated and other advantages of an essentially economic nature, the process of the invention affords a wide of flexibility in the types and quality of the products capable of being produced, through control over the molten metal primary input and through blending and other operations which are possible after the primary molten metal component has been converted to its intermediate, powder stage. This is of particular importance in that it enables the metal product to be specifically tailored to the desired end use, rather than accommodating the end use to the available means as has been more common heretofore. Improved product quality is realized not only through close control of the metal refining and analysis adjustment, made possible by the integrated nature of the process, but also by the avoidance of defects otherwise arising through the conventional ingot casting, rolling and processing.

Generally stated, the process of the invention involves the preparation of a desired analysis molten iron or steel, advantageously as pure as economically feasible, which procedure includes the appropriate refining of the metal or, in certain cases, a desired analysis adjustment. The molten metal is transferred directly to an atomizing chamber, in which one or more streams of the metal are intercepted by high-pressure jets of liquid, usually water, and the molten metal is converted to a desired powder form. At this stage of the process, and throughout all subsequent stages, the powder is maintained in a controlled ambient to minimize oxidation. This controlled ambient is maintained until the powder has been converted to a desired strip or bar form at a temperature below that at which oxidation readily occurs.

After refining of the molten steel or iron and conversion of it into desired high purity powdered metal, the powder, entrained in its cooling water, is fed to a separator, which removes the majority of the water constituent. The dewatered but still wet powder is then dried and screened with respect to particle size, and the dried powder is transferred to suitable holding bins or hoppers from which it is controllably fed into the strip forming stage of the process.

The powder is drawn from the storage bins in a precisely controlled manner and, where desired, is blended with appropriate alloying powders and/or additives. The powder or blended powder may be then fed through a preheating zone, which heats the powder to a temperature at which the powder tends to become soft and plastic without, however, becoming too sticky to process. Thereupon the heated powder is directed with controlled rate and distribution between a first stage of compacting rollers which compress the powder into a so-called green strip which is self-supporting, although weak, and has a density of about 70 to 95 percent.

The partially compacted green strip is directed into a special heating chamber, in which the green strip is brought up to a higher temperature, sufficient to enable

a second stage of compacting to be carried out, to reduce the strip to substantially 100 percent density. In addition, the heating chamber represents an ideal place for subjecting the metal to various reactive treatments, since the metal is still in a highly porous form. Such reactions as carburizing, decarburizing, deoxidation, nitriding, chromanizing, nickelizing, etc., may be carried out with high efficiency, because of the porous nature and high area exposure of the partially compacted metal. In addition, and of particular practical significance, it is possible at this stage to infiltrate the porous metal with dissimilar metals of lower melting point, such as the infiltration of porous iron with copper, for example.

After compacting to substantially 100 percent density, the strip has substantially conventional characteristics. Because it is at an elevated temperature at this point, and it is still subject to the protection of the controlled ambient, the strip is additionally hot-rolled in one or more stages to a desired gauge, which typically could be well below the conventional hot-rolled gauges, because the starting strip thickness is considerably less than in the case of conventional hot-rolling procedures.

After cooling to reduce the likelihood of oxidation, the strip is brought out into the open atmosphere, subjected to such optional treatments as may be appropriate, such as cold-rolling to impart desired surface characteristics or temper, and then sheared or coiled, as desired.

As will be made more evident, the output of the new process need not be a hot-rolled strip, but may be in the nature of a porous, sintered material, an infiltrated material, etc., and the initial formation of the powder into compacted condition may be controlled to produce bars, rods, etc.

For a more complete understanding of the invention, reference should be made to the following detailed description and to the accompanying drawing, in which:

FIG. 1a and FIG. 1b together constitute a greatly simplified, schematic representation of a process according to the present invention for the direct and continuous conversion of molten metal to substantially finished products, such as strip, bars, and rods;

FIG. 2 is a fragmentary cross-sectional view of a modified and advantageous form of atomizing chamber for making metal powders;

FIG. 3 is a fragmentary cross-sectional view taken generally along line 3—3 of FIG. 2;

FIG. 4 is a fragmentary cross-sectional view illustrating an improved arrangement, according to one aspect of the invention, for feeding preheated metal powder into a set of compacting rolls; and

FIG. 5 is a fragmentary cross-sectional view taken generally on line 5—5 of FIG. 4.

Referring now to the drawing, the reference numeral 10 designates a body of molten metal, which is being refined or adjusted as to analysis in a suitable vessel 11. The vessel 11 may be any suitable facility for treating a molten metal body 10, and typically the vessel will be an open hearth furnace, an electric furnace, an L-D converter, or the like suitable for refining steel. In the processing of steel, to which this invention is particularly directed, the vessel 11 advantageously will perform a refining function, to produce a molten iron of the highest practicable purity, even though it may be necessary or desirable, later in the process, to reintroduce carbon or other alloying agents.

At appropriate times, the refined and/or controlled analysis molten metal 10 is discharged from the vessel 11, typically into a suitable ladle 12, by means of which the molten metal is conveyed to and controllably discharged into an atomizing vessel designated generally by the reference numeral 13. In the specifically illustrated system, the vessel 13 includes an upper housing section, forming an atomizing chamber 15, and a lower housing section 16, forming a collection or receiving chamber. In the top wall of the upper housing section is mounted

a receiving crucible 17, provided in its bottom area with one or more (advantageously a plurality) discharge openings 18 for directing a plurality of small, discrete streams of the molten metal into the atomizing chamber 15. Desirably, the openings 18 are of about ¼ inch diameter, and a diameter in excess of about ½ inch probably would be too large for an atomizing chamber of typical proportions. A pair of water discharge nozzles 19 are disposed in suitable array within the atomizing chamber and are arranged to direct high pressure (e.g., upwards of 400 p.s.i.) streams of atomizing water inward and downward, toward and into intercepting relation to the metal stream discharged from the receiving crucible 17.

Advantageously, the relationship of the molten metal stream to the atomizing water jets is such that the jets forcibly disperse and quickly quench the molten metal and thereby produce predominantly sharp and irregular powder particles, rather than spherical particles. In this respect, because of surface tensions and other influencing factors, the atomized molten metal has a tendency to form substantially spherical powder particles which are less desirable for subsequent compacting into metal products because of the inability of spherical particles to pack closely and to interlock with adjacent particles. The more desirable irregular particles may be achieved in accordance with the invention by utilizing advantageous forms of quenching streams, issued at sufficiently high water jet velocity, and discharging the molten metal from the receiving crucible in sufficiently small individual streams.

In accordance with one of the more specific but nevertheless significant aspects of the invention, the atomized powder particles are produced in predominantly irregular form capable of efficient interlocking by so directing the water and metal streams as to prevent substantial contact between the issuing metal streams or metal droplets and small droplets or bubbles of water. This is accomplished in accordance with the invention by so designing and constructing the water discharge nozzles 19 as to cause them to issue streams of quenching water in the form of solid sheets, rather than in the form of sprays comprised of many individual streams or droplets. To this end it is advantageous to utilize a nozzle having an elongated discharge slot of, for example, about ½ inch in length and ½ inch in thickness. The nozzle 19, as shown in more detail in FIG. 3, is advantageously adapted, when operated under appropriately high pressure (typically about 500 p.s.i.) to issue a fan-shaped solid sheet of water, as indicated at 70 in FIG. 3. In an advantageous installation, the solid sheet of water will fan out to a width of about 6 inches and a thickness of about ¼ inch, at a distance of about 12 inches from the nozzle.

A cooperating pair or pairs of water discharge nozzles 19 advantageously are so arranged that their downwardly and inwardly directed sheet-like streams of water intersect to form a V-shaped trough, with the apex of the trough being located directly below the molten metal discharge opening 18, such that the discharging streams or droplets of molten metal drop generally symmetrically into the trough.

At the point at which the water streams 70 converge and intercept the descending body of molten metal, there is a substantial tendency for the water to bubble and froth, due in some degree simply to the force of the converging streams and in some degree to the effect of the molten metal being intercepted by the water. I have found that the formation of bubbles and froth at this point is significantly detrimental to the formation of proper powder particles, because of undesirable steam generation and for other reasons. Thus, the atomizing installation of the invention incorporates, in addition to nozzles adapted to issue solid sheets of quenching water, an arrangement in which the nozzles are disposed at a sufficiently small angle to the vertical effectively to prevent bubbling and frothing at the confluence of the water

and metal streams. In an actual operating installation, a disposition of each nozzle 19 at an angle of 26° to the vertical was found to produce particularly satisfactory results as regards the formation of predominantly irregular and sharply angular powder particles. With the nozzles 19 disposed at such a small angle, the issuing water streams tend to join smoothly and descend as a single stream into the lower section of the housing.

The atomized particles of refined metal drop into the collecting chamber formed by the lower housing section 16 and are collected in the contained body of cooling water designated by the numeral 20. The powder particles are periodically (or continuously, if desired) removed from the collecting chamber by suitable means such as a pump 21 which pumps away the cooling water along with entrained powder particles.

For certain processes, and particularly for the production of high quality iron or steel bars and strip, it is desirable to effect vacuum degassing of the molten metal, and this is accomplished by placing the atomizing chamber 15 under an appropriate vacuum, as by means of a vacuum pump 22. The application of a vacuum to the atomizing chamber 15 is advantageous in a number of respects. First, the exposure of the molten metal streams to the evacuated atomizing chamber causes the streams to literally burst apart, making it easier for occluded gases to be released from the metal. Second, the reduced ambient pressure within the chamber establishes a greater pressure differential relative to the vapor pressures of the gases to promote their release from the molten metal. Partial evaporation of the chamber 15 also significantly improves the efficiency of the atomizing operation by enabling increased areas of the metal to be initially contacted by the high pressure water jets and by causing the molten metal to be drawn through the opening 18 at a greater velocity and rate of flow than would be realized under corresponding conditions with gravity flow alone.

In addition to the evacuation of the atomizing chamber 15, or in place thereof, it is desirable to introduce a controlled atmosphere into the vicinity of the atomized metal particles. In a typical installation, it will be desirable to introduce into the atomizing chamber an inert gas, such as argon, for example, so that the particles are enveloped in a controlled, inert ambient to prevent oxidation or nitrogen pick-up. Naturally, if the atomizing chamber is being maintained in an evacuated condition, the rate of flow of the controlled atmosphere in the chamber will be relatively low, so as not to entirely balance the effect of the evacuating pump 22. For this purpose, suitable regulating valve means 23 may be provided in the inlet pipe 24 for the controlled atmosphere.

In some instances, and particularly where vacuum degassing of the molten metal is practiced, it may be desirable and advantageous to introduce a reducing ambient atmosphere into the atomizing chamber. In such a case, hydrogen gas may be controllably introduced to combine with and neutralize the oxygen released during degassification of the molten metal.

In an advantageous alternative form of atomizing chamber, shown in FIGS. 2 and 3, partial evacuation of the upper housing section 71 is effected through the action of the high pressure water streams 70 passing through an orifice 72 in a separator plate or diaphragm 73 which divides the top and bottom sections of the atomizer housing. The converging jets are arranged to meet in the region of the orifice 72, which is of a size and shape to closely accommodate the well-defined water streams.

As indicated in FIG. 1a, the cooling water and the iron powder particles entrained therein are discharged by the pump 21 through a conduit 25 and to a dewatering unit 26, which may be a conventional settling basin, filter, or centrifuge. Advantageously, the entrained particles are first passed through an apparatus, such as a separator 27, by means of which low density impurities, such as

slag, furnace refractories, and the like, are removed from the higher density metal powder and discharged through an outlet 28.

The dewatered metal powder, which is still, of course, very wet (e.g., 1 percent to perhaps as high as 15 to 20 percent water content) and has a viscous consistency, somewhat like mud, is directed through a conduit 29 or otherwise to a drying and screening chamber 30, in which the powder is heated to a temperature in the region of 300° F. or over to effect water evaporation.

Advantageously, the water supplied to the system, for atomizing, cooling, and transporting of the iron powder, has suitable additives or treatments to reduce its gas content (principally oxygen and nitrogen). The water thus serves as a temporary protective ambient to prevent oxidation or nitriding of the powder during atomization and during the period it is submerged.

In accordance with one aspect of the invention, the iron powder introduced into the drying and screening chamber is exposed to a controlled, inert ambient, typically nitrogen or argon gas, for example, and is maintained in a controlled ambient until formation of a substantially finished sheet, strip, or bar, and its emergence from the process at a temperature below that at which oxidation readily occurs. Thus, referring again to FIG. 1a, an inert ambient atmosphere such as nitrogen is introduced into the drying and screening chamber 30 through a suitable conduit 31, so that the iron powder is exposed to the atmosphere during the drying process.

As the powder becomes dry, it is passed over suitable screening means (not specifically shown). In some cases, it may be desirable to classify the powder into various size ranges. However, in the process of the invention, it is usually more desirable to simply screen the particles to pass all those particles smaller than a given size and reject all those particles of greater size. Advantageously, all particles capable of passing through a 40 mesh screen are accepted as a group, and all larger particles are discharged for rework or discarding. It is desirable in the process of the invention to work with intermixed particles of various sizes, since the finer particles pack in between the larger particles and facilitate the compacting of the powder particles into a dense, coherent strip of metal.

In the continuous procedure of the invention, the dried metal powder particles passing through the screening chamber 30 are conveyed, advantageously by gas entrainment, through a conduit 32 to temporary holding bins 33, the latter being supplied with an inert atmosphere, such as nitrogen, as through an inlet conduit 34. The temporary holding bins 33 function to absorb temporary fluctuations in the rate of powder making and the rate of subsequent strip formation, as will be understood.

Associated with the outlet 35 of a holding bin is a blending chamber 36, in which the primary metal powder particles may be mixed and blended with desired additives, such as detergents, activators, lubricants, binders, or, in appropriate cases, other metal powders or alloying agents. The additives typically may be introduced through an inlet facility 37. Also, reducing atmospheres may be added which will become effective when the powder is later preheated for compacting.

The blending operation is of particular significance in a typical process according to the invention, because of the advantageous controls provided over the final metal composition, as well as the ability to promote or facilitate certain of the subsequent operations. For example, the addition of appropriate detergents and activators can significantly reduce the times and temperatures required for subsequent heating and/or sintering operations. Further, the detergents and activators, as well as various desirable lubricants and binders, can greatly facilitate the operation of compacting the powder to form a green strip. Of perhaps even greater importance, however, the blending stage permits alloying powders to be mixed with the otherwise high purity metals to achieve a variety of

advantageous effects, including the formation of alloys otherwise impossible or impractical to produce.

By way of example, in the production of controlled analysis steel strip in accordance with the invention, the steel first would be refined to iron of the highest practicable purity (particularly as regards carbon content), advantageously to a carbon content of 0.05 percent or less, so that the basic powder would be as soft as possible for proper subsequent compacting into strip form. At the blending stage, desirable percentages of carbon in various forms or high carbon steel powder may be blended with low carbon iron powder, so that the desired average amount of carbon is present in the final steel strip material. In this respect, while the formation of a metal strip directly from a higher carbon content steel powder would present substantial difficulties, because of hardness of the powder, such difficulties are effectively avoided by blending of low carbon iron or steel and high carbon steel powders to achieve a desired average carbon content in the final strip.

Another particularly advantageous blending procedure which may be followed in the process of the invention is the alloying with iron or steel of relatively high percentages of copper, which can result in significantly increased tensile strength and fatigue endurance of the final product, as well as substantial improvements in its corrosion resistance. By conventional steel making practices, it has not been practicable to utilize copper as an alloying constituent in percentages greater than 0.5 percent, at least without introducing other complicating alloy constituents, because of a tendency of the copper to separate out upon heating of the steel. By contrast, in accordance with the process of the invention, virtually any percentage of copper may be added to the metal in the blending step (or in a subsequent infiltration procedure to be described), and true alloy characteristics are realized in the final material.

As may be appreciated from the foregoing, the blending stage offers an opportunity for the convenient preparation of an extremely wide variety of alloy combinations, enabling an extra-ordinarily wide range of end products to be produced. Further, the blending of various compositions may be carried out efficiently on a small quantity basis, so that the metal products may economically be prepared especially for particular end uses.

The metal powder can be compacted directly by being controllably fed to the compacting rollers 39, but the use of a preheating apparatus 38 will provide for increased production rates and for desirable operating flexibility. Precise feed control is important in order to achieve a uniform rate of feed toward the compacting rollers 39 and to assure that the rate is uniform across the entire width of the compacting rollers. Where iron or steel making powder blends are employed in the procedure, the feed control facility (not specifically illustrated) may include appropriate magnetic pump or roller means, for example.

In the preheating chamber 38, the powder particles are heated to a point at which the particles will tend to soften and plasticize, although the temperature should be maintained below that at which the powder mass will become too sticky to process. With a steel making blend of particles, an advantageous preheating temperature is in the region of 1000° F., or over. Experience indicates that the maximum temperature possible is advantageous but this maximum temperature will vary with different metals or alloys and the methods used.

Advantageously, heat imparted to the powder particles during the drying stage is utilized to assist preheating, where practicable. This is accomplished by delivering the newly dried powder promptly to the preheat stage while maintaining the powder conveying and holding facilities insulated against rapid heat loss.

An advantageous form of preheating and feeding system is illustrated in FIGS. 4 and 5, which provides for

a high rate of feed while assuring uniform distribution as well as uniform heating of the powder. The equipment includes a supply chamber 74, in which the powder is given a first stage preheat to as high as about 900° F. The partially preheated powder is then directed through a plurality of spaced distributing tubes 75 which, collectively, form an effectively continuous discharge outlet immediately above the nip of the compacting rollers 39.

The distributing tubes 75 are provided with heater units 77 which impart a second stage preheat to the powder, raising it (in the case of iron or steel making blend) to its final preheat temperature of 950° F. or higher. The distributing tubes, which may be on the order of 1 inch in diameter or less, provide for closely and individually controlled and uniformly effective heating of the powder.

As the powder increases in temperature, entrapped gases expand and must be removed. Accordingly, the system of the invention advantageously includes evacuating tubes 78 positioned concentrically within the distributing tubes. They are arranged to efficiently remove air or gases displaced from the powder in the course of feeding, preheating, and compaction.

At the preheat temperatures used in the process, reducing gases previously added to the powder become effective in reducing oxides that may be present. Thus, the powder preheating operation, as carried out in accordance with the invention, serves not only to soften the powder for more advantageous compacting, but eliminates the need for annealing and oxide reduction operations normally performed in conventional powder production procedures.

Control of the flow of iron or steel powder through the distributing tubes 75 may advantageously be effected through the use of means such as magnetic coil means (not shown) around the tubes. By establishing a downwardly travelling magnetic field, the powder will be, in effect, "pumped" downward. Magnetic means also may be used as valves to effect individual control over the downward flow of powder. Any tendency of the hot powder to stick to the tubes can be reduced by the application of vibrators 79.

In the process of the invention, the preheated powder particles are compacted by the rollers 39 to a density in the range of 70 to 95 percent that of solid metal strip, and advantageously this is accomplished using compacting rollers having a diameter greatly in excess of the compacted strip thickness (for example on the order of 100 to 300 times the thickness of the initially compacted strip). The product emerging from the first stage of the compacting rollers 39 is referred to as a green strip. It is reasonably integrated and is self-supporting but is still quite weak relative to finished metal strip.

Following initial compaction, the green strip is diverted about a guide roller 41 and directed into an elongated heating chamber 42, in which the green strip is heated to a higher temperature, in the range of 1600° F. to 2200° F. The green strip, which may be partially sintered within the heating chamber 42 where desired, is in any event in a desirably heated condition for further compacting, upon its emergence, by means of final stage compacting rollers 43. The rollers 43 serve to compact the heated strip to substantially 100 percent density, and the diameter of the rollers advantageously is over 1000 times the thickness of the densified strip. The large diameter rollers more effectively densify the porous strip than smaller rollers because of their more gradual compressing action over a longer period.

The strip passing through the heating chamber 42, being in a porous condition and at high temperature, is ideally receptive to a variety of gas reaction treatments, such as carburizing, decarburizing, deoxidation, nitriding, chromanizing, nickelizing, etc. These reaction treatments may be advantageously carried out by introducing appropriate gases into the heating chamber or into se-

lected, divided regions of the heating chamber. In this connection, the chamber may be made as long as is necessary and desirable to effect the necessary heating of the strip and its exposure to the reacting medium. Further, advantage may be taken of the heated, porous condition of the green strip within the heating chamber to cause the strip to be infiltrated with a lower melting point metal. Iron or steel strip, for example, may be readily infiltrated with molten copper, such that the product emerging from the heating chamber is a substantially solid material of unique properties. Various additives from the blending stage also bring about advantageous effects. Detergents and activators promote sintering or hot compacting, and compounds such as dissociable hydrides release protective or treating gases in the immediate vicinity of the particles.

In the production of iron or steel strip in accordance with the invention, it is contemplated that the densified strip, indicated by the reference numeral 44 in FIG. 1b, will be reduced to a substantially finished size or thickness, and one or more hot roll reduction stages 45, 46 advantageously are provided for this purpose, located immediately following the final stage compacting rollers 43, to receive the densified metal while it still retains the heat of the chamber 42. In this connection, the hot-reduced form of a steel or iron strip or bar, designated by the numeral 47 in FIG. 1b, may readily fall well within the size ranges conventionally achievable only by cold reduction processes. Thus, in the manufacture of iron and steel strip, following conventional procedures, the practical lower limit of hot-rolled reductions is to a strip thickness of 0.060 inch, and even this lower range is very difficult to achieve. With the procedure of the invention, however, since the thickness of the fully densified strip 44 may be readily controlled at the first compacting stage, the hot reduction may be carried out to minimum strip thicknesses on the order of 0.010 inch without difficulty. Similar advantages are realizable, of course, in the manufacture of substantially finished bars and rods.

In accordance with one aspect of the invention, the iron or other powder is maintained under an inert ambient from the time of its delivery as dried powder to the holding bin 33 to the time of its emergence as a substantially finished product at a temperature below that at which oxidation will readily occur. To this end, it is appropriate to maintain the strip wholly enclosed in a suitable chamber 48 (or series of chambers) which, in effect at least, embraces the strip from the point of its initial formation to the point of its emergence at a relatively low temperature. The chamber 48 is supplied, as through a conduit 49, with a suitable inert atmosphere, such as nitrogen or argon. In this connection, it may be desirable to embrace the strip with a series of individual chambers, rather than a single large chamber as schematically illustrated in FIG. 1b, to achieve various practical conveniences and to minimize requirements of the gas forming the controlled ambient. Further, while nitrogen is a desirable gas for many stages of the strip forming process, it tends to react with iron or steel at higher temperatures, and other gases, such as argon or prepared atmospheres, may be desired for protecting or treating the strip during its passage through the heating chamber 42.

The strip 44 may be protected from oxidation as it travels from the furnace 42 to the cooling sprays 50 by flame curtains, which are reducing. However, it may be desirable in some cases to impart a controlled oxide coating on the strip surface.

Prior to the emergence of the substantially finished strip from its protective ambient, the strip may advantageously be subjected to cooling sprays 50, which serve to reduce the strip temperature to a range of about 300° F. to 400° F. At this temperature, there is very little tendency for iron or steel strip to oxidize.

The cool, substantially finished product is typically directed to a rolling stage 51, for cold reduction, for temper rolling, or for desired surface characteristics. Thereafter, the finished product is directed to a flying shear 52, for example, for cutting into sheets, finite bars, etc., or to a coiler, indicated at 53, for coiling into longer, continuous lengths. Typically, two coilers would be employed to accommodate uninterrupted operation.

In the event that the production of powder exceeds the output of the product-forming end of the continuous process, or where otherwise desirable and expeditious, some of the powder discharged from the drying and screening chamber 30 may be diverted out of the system and bagged or otherwise stored for subsequent use. To this end, the system may include an auxiliary conduit 54, control valve means 55, and a bagging or other storage installation, schematically indicated at 56. Advantageously, the stored or bagged powder is maintained under a controlled ambient for prevention of oxidation. This is usually done by inserting moisture absorbing material such as packages of silica gel.

The process of the invention, while having applicability to a number of metals, is especially advantageous for the conversion of molten iron or steel to iron or steel products, such as strip, because of the significant economic and procedural advantages which, in the case of the extremely high temperatures involved in the manufacture of iron and steel, are of critical practical significance. It is also of significant usefulness in connection with the production of copper products and of products formed of alloys of 50 percent or more copper or iron.

In a typical operation according to the invention in which the starting raw material is scrap steel, the analysis of non-ferrous elements in the starting material may be somewhat as follows:

	Percent
Carbon -----	0.18
Manganese -----	0.57
Sulfur -----	0.032
Silicon -----	0.04
Chromium -----	0.01
Molybdenum -----	0.01
Copper -----	0.03
Phosphorous -----	0.015

A starting material of the above analysis would advantageously be refined in the vessel 11 to a condition of high purity such that the power product formed with the refined steel has an approximate analysis as follows:

	Percent
Carbon -----	0.026
Manganese -----	0.120
Sulfur -----	0.027
Silicon -----	0.050
Chromium -----	0.000
Molybdenum -----	0.010
Copper -----	0.030
Phosphorous -----	0.010
Oxygen -----	0.410
Nitrogen -----	0.010
Acid insolubles -----	0.280
Iron -----	99.18
Sieve analysis (through 80 mesh sieve) -----	90.10

The resulting low carbon powder is useful and indeed especially desirable in its subsequently produced strip form for small electrical motor manufacture, because of the particularly good magnetic properties of the strip, coupled with its low cost. Even greater advantages are realized for this purpose when a controlled surface oxide coating is imparted to the strip.

By using selected quality raw materials, such as pig iron of preferred analysis, powder of even greater purity can be produced without difficulty. A typical approxi-

mate analysis of such a higher purity powder is as follows:

	Percent
Carbon -----	0.015
Manganese -----	0.008
Sulfur -----	0.020
Silicon -----	0.038
Chromium -----	0.000
Molybdenum -----	0.001
Copper -----	0.025
Phosphorous -----	0.010
Oxygen -----	0.320
Nitrogen -----	0.010
Acid insolubles -----	0.025
Iron -----	99.30
Sieve analysis (through 80 mesh sieve) -----	98.00

Low carbon powder of the foregoing typical analysis may be alloyed or otherwise modified by powder additions at the blending stage, such that entirely new metal and metal product fields may be opened up. Similarly existing types of metal products, heretofore prohibitively costly or otherwise economically disadvantageous, may be made available on a practicable basis utilizing the procedures of the invention. For instance, stainless steel products such as strip, bars, or rods can be advantageously produced by this method because of the reduced number of operations necessary.

A particularly advantageous practical aspect of the process of the invention resides in the fact that the process may be performed without interruption from the molten metal stage to the substantially finished product stage with close control over analysis of the molten and blended metals and over the composition of the final strip. In the case of steel products, significantly increased quality may be realized through the elimination of such defects as pipe, blow holes, segregation, cracks, and non-metallic inclusions, formed when steel is conventionally cast into ingots, and from the elimination of other defects caused in the many heating, rolling, handling, and other numerous operations conventionally required to produce a substantially finished product.

In the manufacture of certain steel products, it is especially significant in the process of the invention that the intermediate stage of the metal is in the form of low carbon iron or steel powder particles, rather than in the conventional form of ingots at one intermediate stage and slabs, blooms, or billets at another intermediate stage. With the procedure of the invention, the same intermediate material—powder of controlled, desired analysis—may be utilized in the formation of strip, bars, rods, etc., and intermediate handling and storage operations are reduced to an ultimate minimum, as compared to conventional steel making operations. The process of the invention also enables the production in commercial quantities of many steel products which heretofore have been unable to be produced, at least otherwise than on a laboratory basis. One important class of steel products which may be produced according to the new process is hot-rolled strip in gauges of less than 0.060 and well down into the range conventionally available as the more expensive cold-rolled strips.

A significant specific aspect of the invention resides in the concept of initially preparing iron or steel powder of highest practicable purity, particularly as regards carbon content, to achieve desirable properties for subsequent compac-

tion into green strip, and preparing an alloy blend by alloy powder additions made prior to the compacting operation. Thus, even where the blending step simply restores certain of the elements removed during refining, significant practical advantages may be realized by reason of the desirable compacting properties of the soft, pure powder, which serves in effect as a matrix for the alloying powders.

It should be understood that the specific forms of the invention herein illustrated and described are intended to be representative only and that certain changes may be made therein without departing from the clear teachings of the disclosure. Accordingly, reference should be made to the following appended claim in determining the full scope of the invention.

What is claimed is:

Apparatus for atomizing molten metal to produce powdered metal particles, which comprises

- (a) means forming a chamber,
- (b) a separator dividing said chamber into a substantially closed upper section and a lower section,
- (c) said separator having an orifice-like opening connecting said chamber sections,
- (d) means for discharging a stream of molten metal downward into said upper chamber section and toward and through said orifice, and
- (e) nozzle means for directing wide, flat and substantially continuous sheetlike high velocity streams of quenching liquid into said upper chamber section and downward at an angle through said orifice,
- (f) said streams intercepting said molten metal and meeting substantially at said orifice,
- (g) said orifice being of a size and shape to relatively closely receive the converging quenching liquid streams and to closely accommodate their downward passage through the orifice,
- (h) the action of said high velocity stream of quenching liquid passing through said opening being effective to partially evacuate said upper chamber section, to effect partial vacuum degassing of the molten metal,
- (i) said metal being disintegrated into finely divided and substantially irregular form.

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