

Jan. 18, 1966

A. ROY ETAL

3,230,074

PROCESS OF MAKING IRON-ALUMINUM ALLOYS AND COMPONENTS THEREOF

Filed July 16, 1962

3 Sheets-Sheet 1

FIG. 1.

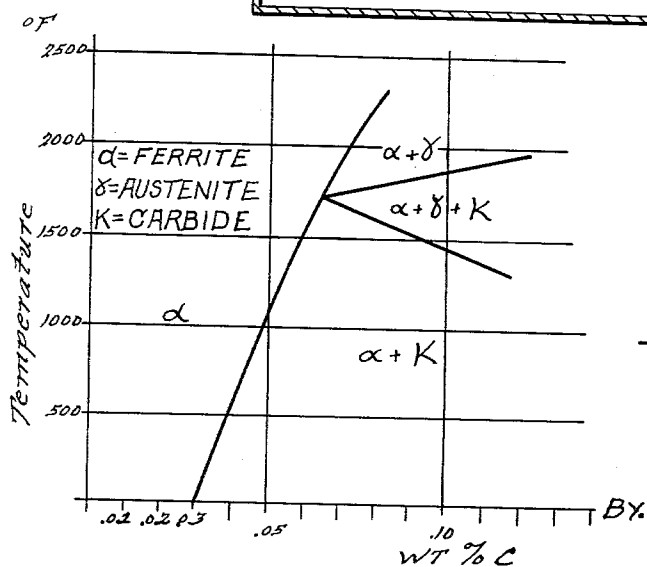
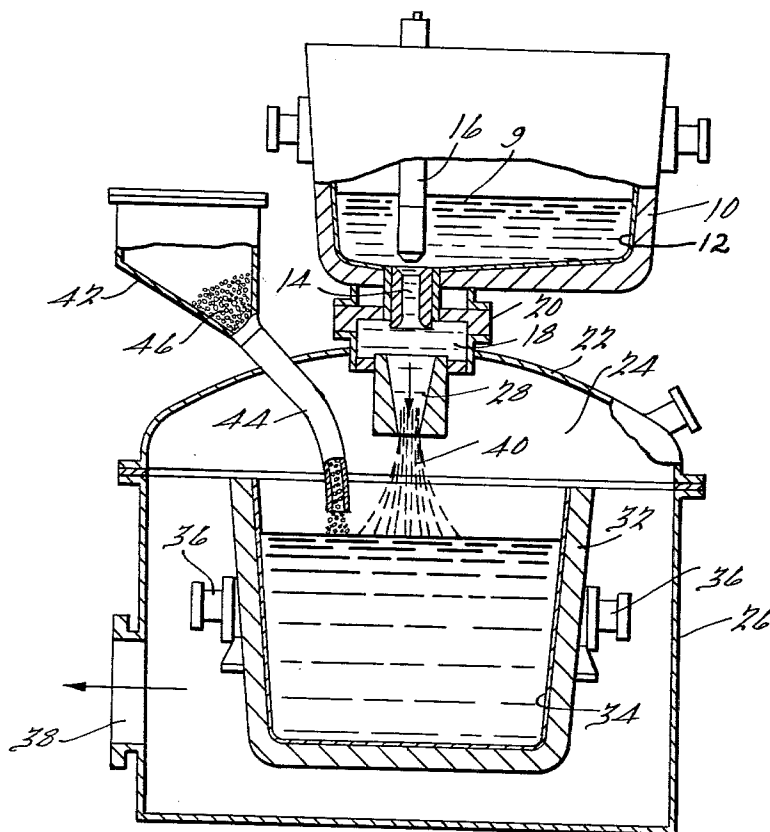


FIG. 4.

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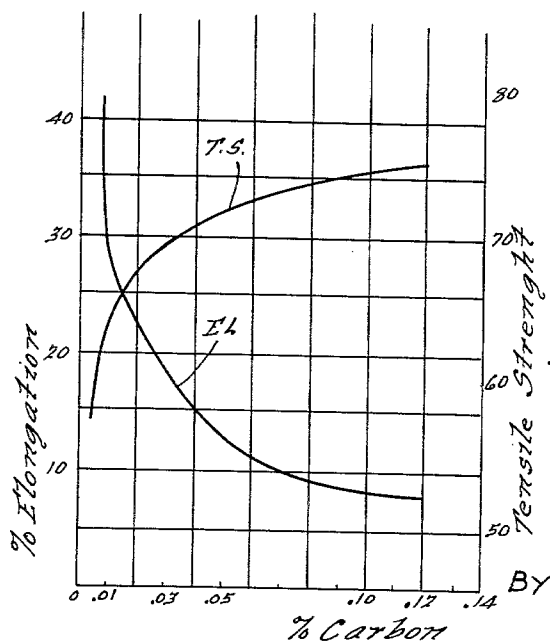
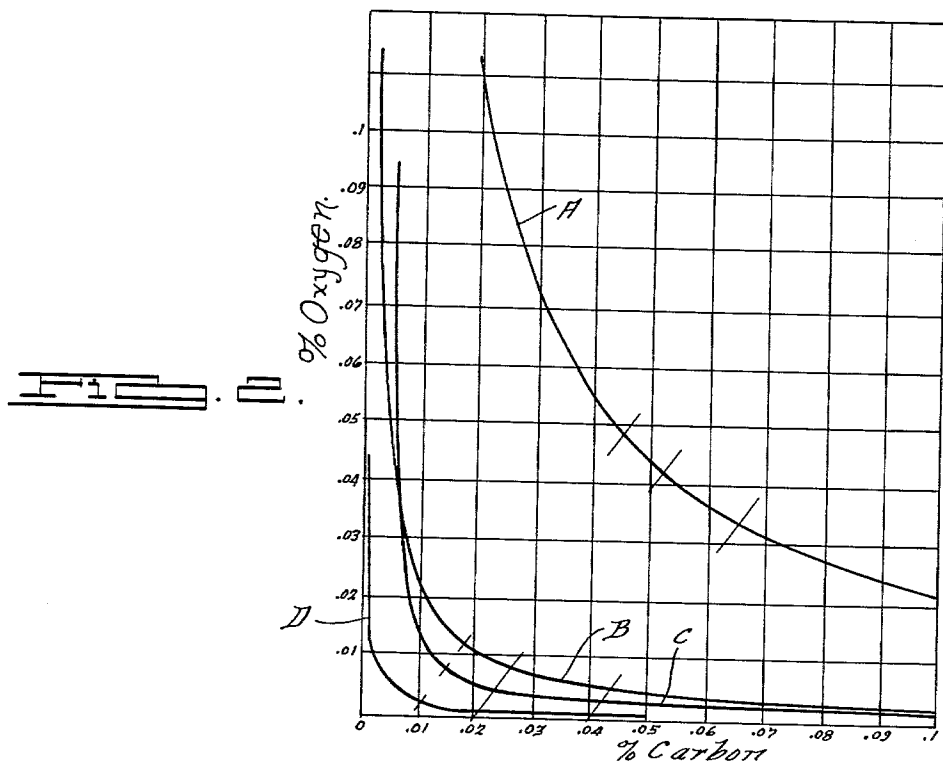
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PROCESS OF MAKING IRON-ALUMINUM ALLOYS AND COMPONENTS THEREOF

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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

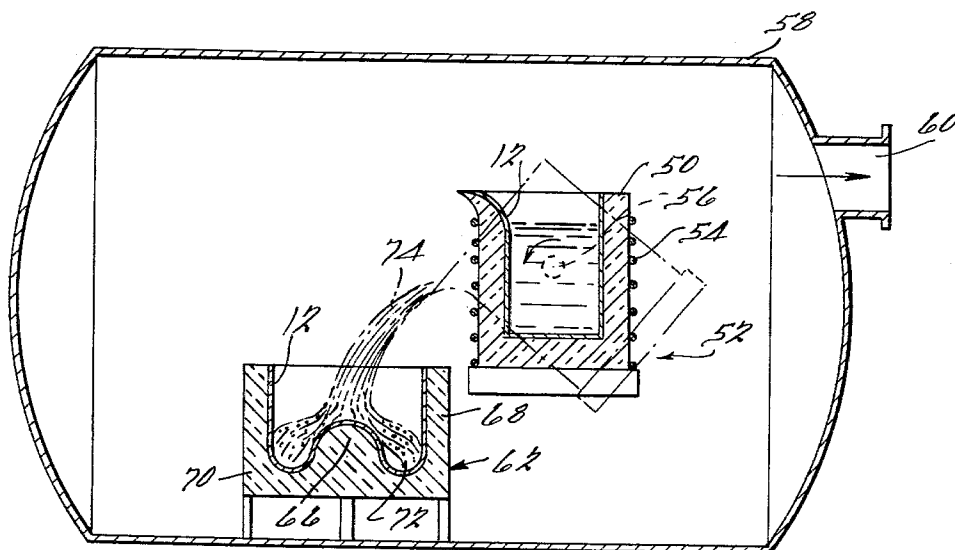


FIG. 5.

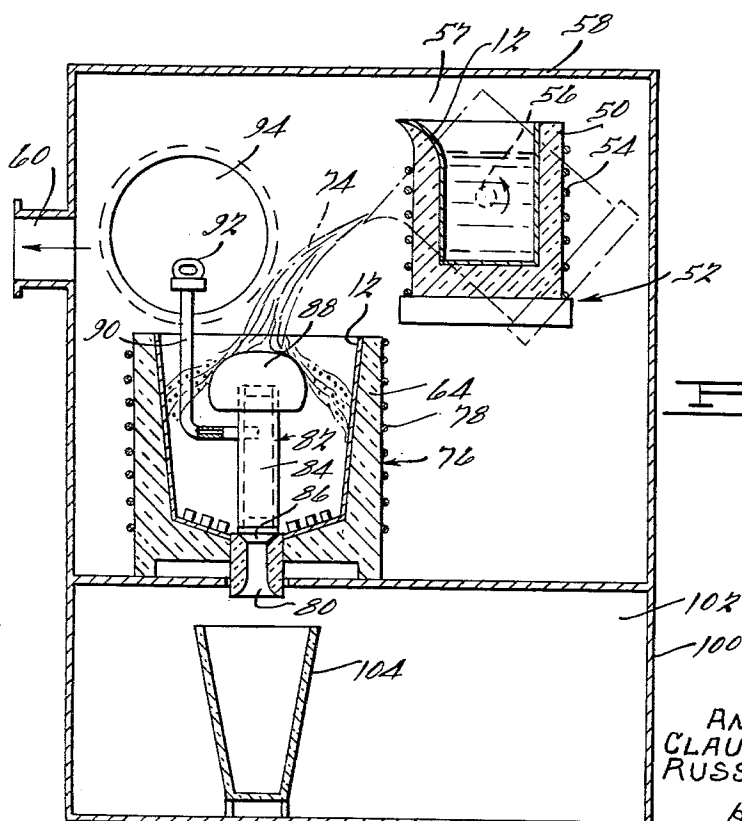


FIG. 6.

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**PROCESS OF MAKING IRON-ALUMINUM
ALLOYS AND COMPONENTS THEREOF**

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Filed July 16, 1962, Ser. No. 209,939

14 Claims. (Cl. 75-49)

This invention relates to ductile iron-aluminum alloys and especially to a process for making the same. It is also concerned with novel procedures for reducing the carbon content of the carbon-containing iron (generally called a steel) base ingredient for such iron-aluminum alloys.

In the pending application Serial No. 655,191 of applicant Amedee Roy and one Walter E. Jominy, filed April 26, 1957, now U.S. Patent No. 3,059,326, granted October 23, 1962, it is set forth that the cold working of iron-aluminum alloys (usually requiring at least about 10%, and in many cases 20% elongation on standard tensile testing specimens at room temperature) is adversely affected by carbon additions or inclusions above about 0.03% to 0.05% by weight.

Moreover, it is indicated that iron-aluminum alloys having in excess of such carbon and containing 10% and more aluminum lack sufficient elongation (have less than about 5% elongation) for room temperature fabrication, and are brittle. It is also there indicated that attempts to reduce room temperature brittleness by the use of vacuum during conventional melting of the iron and aluminum resulted in some improvement in the hot rolling characteristics of the material and that where in such operations hydrogen was passed through the melt or carbon additions made thereto to produce this result, some further improvement in ductility was feasible. These improvements are, however, costly to effect and do not produce optimum ductility characteristics.

The present invention is directed to a new, and novel, process for producing iron-aluminum alloys of substantial uniformity and ductility characteristics, capable of being cold or hot worked and to the alloys per se having these properties.

An object of the invention is to provide a process involving first providing a carbon-containing iron melt capable of combination with substantially pure aluminum to form a ductile iron-aluminum alloy and then adding to and mixing with the molten iron a predetermined amount of such aluminum.

A particular object is to provide a process of making ductile iron-aluminum alloys wherein aluminum in solid form is added to molten iron containing less than 0.03% carbon by weight.

Another particular object is to provide a process for reducing the carbon content of a body of iron containing in excess of 0.03% carbon by weight, which iron is to be alloyed for producing a ductile iron-aluminum alloy comprising melting a body of said iron, transforming said body of molten iron into a moving stream thereof, dispersing said stream and subjecting said dispersed stream to vacuum to remove oxides of carbon therefrom.

A further object is to provide a process as in the preceding object wherein the body of iron is made to contain sufficient oxygen for the critical oxygen equilibrium requirement for the amount of carbon in the melt.

Another object is to provide a process of making iron-aluminum alloys involving the treatment of an iron melt to reduce its carbon content to within stated critical limits, and to thereafter add to the molten iron in predetermined amount substantially pure aluminum in solid form, and in a manner to effect its uniform distribution in the melt to provide an ultimate ductile iron-aluminum alloy.

An additional object is to provide a process of producing ductile iron-aluminum alloys as in the preceding object, wherein the reduction in carbon is effected by vacuum degassing of a molten stream of steel to which critical amounts of aluminum are subsequently added while the latter is still molten.

Another object is to provide a process of producing ductile iron-aluminum alloys involving treating a steel melt under vacuum conditions to reduce the carbon content to below about 0.03% by weight, and thereafter adding substantially pure aluminum in solid form in amount between about 3 to 12% by weight to produce a ductile iron-aluminum alloy, said steel melt containing or having added thereto during processing sufficient soluble oxygen according to the equilibrium requirements of the initial carbon content of the melt for effecting said carbon reduction.

A further object is to provide a process as in the preceding object wherein the steel melt initially contains carbon in amount less than about 0.2% by weight.

Still another object is to provide a procedure for reducing to below about 0.03% the carbon content of a molten steel containing or to which soluble oxygen has been added, comprising directing the molten steel through a restricted orifice into a chamber subjected to vacuum to produce a particle stream thereof, wherein the soluble oxygen combines with soluble carbon to form carbon monoxide and some carbon dioxide gas, and subjecting the stream to a vacuum sufficient to remove these gases from the stream.

A further object is to provide a method of producing ductile iron-aluminum alloys from ingredients including a high carbon-containing steel which comprises initially melting and treating the steel under a protective blanket of slag or gas and at atmospheric pressure to effect a boil of the melt to reduce the carbon content thereof; then forming the molten steel into a fan-like stream, and subjecting the stream to vacuum degassing to further reduce the carbon content and then adding aluminum in predetermined amount, in solid form, to the thus treated steel, and under conditions inhibiting volatilization of the aluminum.

A specific object is to provide a process comprising melting a body of iron by induction heating while subjecting said body of iron to vacuum, after melting said iron, separately heating a solid mass of aluminum by induction heating and combining said molten iron with said aluminum into a uniform mixture while continuing the application of said vacuum.

Other objects and advantages of the invention will appear from the following description and from the drawings, wherein:

FIGURE 1 is a schematic sectional view in elevation showing a form of apparatus by which the present invention may be performed;

FIGURE 2 is a graph showing the relationship between carbon and oxygen contents in iron at 2800° F. at various pressures;

FIGURE 3 is a graph showing the effect of carbon on certain physical properties of a wrought iron-aluminum alloy containing 6% aluminum annealed for one hour at 1500° F. and air cooled;

FIGURE 4 is a graph showing the Fe-Al-C diagram for an iron-aluminum alloy containing 6% aluminum; and

FIGURES 5 and 6 are schematic sectional views of additional forms of apparatus by which features of the present invention may be obtained.

The invention is based upon a number of considerations, in part theoretical and in part derived by experimentation. For example, it is founded first, on the recognition that the carbon content of a steel melt is susceptible to reduction by combining it with other elements to form metallic compounds upon cooling, and that when

soluble oxygen is present in the melt it may, under proper conditions, interreact with carbon to produce a removable gaseous oxide such as carbon monoxide (CO) and some carbon dioxide (CO₂); secondly, upon the fact that the extent to which the latter is possible is dependent upon there being sufficient soluble oxygen in the melt, and preferably an amount equal to or exceeding the critical oxygen equilibrium condition for the amount of carbon present in the melt; thirdly, upon the finding that substantial dispersing or particulating of the melt occurs when a moving fluid body thereof is permitted to impinge upon a bulbous protuberance or to be released as a stream into a low pressure medium from one where it is subjected to atmospheric or higher pressure, which dispersing and/or particulating is conducive to the formation of carbon monoxide and some carbon dioxide by the soluble carbon and oxygen of the melt and that the simultaneous application of sufficient vacuum under these conditions also facilitates this formation of gaseous oxides and furthermore facilitates their expeditious removal from the melt; and fourthly, upon the finding that for optimum alloying, the aluminum additions should be made to the iron melt in solid (i.e., unmelted) form after the iron melt has been conditioned for allowable critical carbon content and preferably in a manner to avoid exothermic reactions and volatilization of the aluminum.

Although iron-aluminum alloys having the desired room temperature fabricability may be produced using for the iron component highly purified electrolytic iron, such is very costly and unpracticable where large quantities are involved. Therefore other commercial steels must be utilized. These normally contain substantial amounts of carbon which must be reduced prior to making the aluminum addition. We have discovered that it is possible to initiate processing with a steel stock containing a relatively high amount, for instance about 0.2% by weight and more of carbon and which may be scrap steel, or by starting processing with steel stock containing a relatively low amount, for instance about 0.1 to 0.2% by weight and less carbon.

If, for example, the charge contains carbon in the high range, for instance 0.6 to 1.0% carbon, as in the case of commercial steel scrap, it will first be treated by conventional melt procedure to reduce the carbon content to a minimum possible in this manner, and thereafter by the vacuum procedures described above to further reduce the carbon content. Thus considering the use of steel scrap and in a large batch the charge is first preferably melted in a suitable furnace at atmospheric pressure, preferably in a furnace chamber or crucible lined with magnesium oxide or other refractory, and with the melt under a blanket of slag (preferably composed of limestone, fluospar, and cryolite) or argon gas, and at a temperature sufficiently high, for example between 2800 and 3100° F., during which any readily combinable soluble carbon and oxygen may react to form carbon monoxide or carbon dioxide and cause an active boil tending to stir the melt into active movement and facilitate escape of the gaseous oxide of carbon through the blanket. Heating the melt for about one hour more or less depending upon melt conditions and the size of the melt will usually suffice.

In order to effect optimum reduction in the carbon content of the steel by this procedure, it is usually desirable to lance the melt with oxygen by blowing oxygen into the melt or by adding oxygen-containing compounds such as iron oxide to provide oxygen to the melt.

The carbon reduction by this process is seldom to a level below about 0.03% and always insufficient for directly utilizing the same in the making of a substantial ductile iron-aluminum alloy such as described above. Accordingly, further treatment of the melt is required. This may for example be carried out in an apparatus such as shown in FIGURE 1 where the fluid charge 9 of the above initial processing has been transferred while

still molten to a ladle 10. The ladle 10 of FIGURE 1 is preferably lined at 12 with magnesium oxide refractory material and has a bottom bell mouth nozzle-like pouring outlet 14 through which a stream of the molten iron may flow and which may be manually closed by a suitable rod stopper 16. No protective blanket is required in the transfer operation, and it and the steps hereinafter described are relatively promptly performed to avoid extraneous heating. It will be understood that heating may be provided if desired.

From the ladle 10 the fluid melt is discharged under atmospheric or higher pressure through the bottom pouring outlet 14 into a small intermediate chamber or cavity 18 provided in a housing 20 secured in the roof or cover 22 of a vacuum chamber 24 defined by a casing 26 and said cover 22. The cavity 18 has a converging nozzle-type discharge outlet 28 at the bottom thereof from which the melt is discharged into an open-top ladle 32, also preferably lined with magnesium oxide refractory material as at 34. The ladle 32 is suitably supported on pivotal trunnions 36 within chamber 24. The chamber 24 into which the melt is directed is subjected through an opening 38, by conventional means not shown, to a vacuum as great as practicable; for example corresponding to a pressure of less than about 0.1 atmosphere. As the melt is released into the vacuum chamber the differential pressure or, stated otherwise, the sudden release of pressure, causes it to be dispersed, automatically fan out and become in effect a stream 40 of many individual droplets or particles of molten metal.

It is found that by this action it is possible to facilitate interaction of the soluble carbon and oxygen remaining in the melt to an extent not otherwise possible. By preference, the dispersed stream 40 of molten metal will be made to travel over a substantial distance, preferably in the order of several feet, since such will further facilitate the reaction between any soluble carbon and oxygen carried in the stream to form gaseous carbon monoxide which will bubble from the stream or be pumped out of the stream by the vacuum applied at 38 and removed from the chamber. It has been found possible by the described step to reduce the carbon of the melt received in the ladle 32 from an amount, for example 0.03% by weight to below 0.002% by weight, depending upon the degree of vacuum employed and the sufficiency of the oxygen in the melt.

The addition of aluminum to the molten iron may be made by injecting it into the molten dispersed stream where it discharges into the melt in the ladle 32 or to an accumulation thereof in the ladle. It may also be made while vacuum still exists in the chamber 24 or while it is subjected to above atmospheric pressure or after removing the ladle from the vacuum chamber.

It is preferred to add the aluminum under a layer of molten iron and while the aluminum, preferably preheated, is in a solid state. The latter is desirable to avoid a high rate of volatilization of the aluminum, which can occur where molten aluminum is added, and a temperature rise by exothermic reaction.

The aluminum addition in amount between about 3% to 12% by weight and preferably between 3½% to 8% but in any case not more than will produce a ductile iron-aluminizing alloy capable of room temperature fabricability may be made, for example through a hopper 42 having a discharge outlet 44 arranged over the mouth of the ladle 32 and controlled to feed or inject predetermined quantities of aluminum pellets or granules 46 into the stream 40 or to an accumulation in the ladle 32, in accordance with the rate of discharge of iron melt from the discharge nozzle 28. Aluminum pig may also be placed in the ladle 32 prior to commencing discharge of the melt thereto, the impingement of the stream 40 aiding in keeping the metals mixed. The use of aluminum wire or rod which can be fed through the means 42 into

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the ladle 32 under the surface of the melt and at a constant rate is also contemplated.

It will be understood that where the steel melt initially contains 0.1% carbon or less, the preliminary treatment of the melt may be omitted and the melt directly subjected to the vacuum stream treatment described.

Instead of using the apparatus of FIGURE 1, for the further removal of carbon from the iron component, the iron melt after the initial "carbon boil" treatment described above may in any known manner be transferred in molten form to the melting ladle 50 of an induction furnace 52 shown in FIGURES 5 and 6 having a current carrying coil 54, and suitably supported as on a pivotal trunnion 56 in chamber 57 of a housing 58 to which a vacuum such as described with respect to FIGURE 1 is applied through the opening 60. It will be understood that if desired the charge of iron scrap may, if not excessive, be initially melted in the furnace 52 and subjected to carbon boil by vacuum to reduce the carbon content.

In either event the molten iron is then either poured into a ceramic mold or receptacle 62 as in FIGURE 5 or into a further induction heated ladle crucible or receptacle 64 as in FIGURE 6.

The receptacle 62 as seen has a central bulbous protuberance 66 defining with the side and bottom walls 68, 70 of the mold a ring-like depression or well 72 into which the molten iron may flow and accumulate. As the poured stream 74 of iron from the ladle 50 strikes the protuberance 66 it is dispersed into a fan-like stream of particles or droplets of molten iron such as in case of the stream 40 in FIGURE 1 facilitating the combining of soluble carbon and oxygen into gaseous carbon monoxide and some carbon dioxide which is thereupon removed from the stream by the vacuum action thereon in the chamber 57. Since the protuberance 66 forms part of the mold bottom it will be recognized that dispersment of the stream 74 by the same is limited by the extent of its projection above the base 70.

This condition is overcome by the arrangement in FIGURE 6 where the ladle or crucible 64 of the induction heated furnace 76 having a current carrying coil 78, is provided with a bottom bell-mouthed pouring outlet 80 closed by a manually or power operable stopper means generally designated by the numeral 82.

As seen the stopper means 82 comprises a hollow stem 84 having a closed stopper and member 86 and a bulbous head 88 which serves to disperse the stream 74 as in the case of the protuberance 66, of FIGURE 5. The stopper means 82 may if desired be liquid cooled by any suitable means. It will be noted that in the FIGURE 6 arrangement the molten iron may accumulate for a considerable depth in the crucible 64 without interference with the action of the head 88. The stopper means 82 may be operated in any suitable manner by the bent rod 90 having an extension 92 in the plane of the drawing which may be fulcrumed in a cover member 94 of the housing 53 and pass through the same so as to be operable externally of the chamber 57 for raising or lowering the stopper means 82.

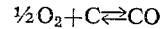
The housing 58 may include a lower section 100 providing a chamber 102 which is optionally provided with vacuum in which a mold or receptacle 104 may be positioned to receive the molten metal from the crucible 64.

Obviously aluminum additions may be made to the molten iron in the receptacles 62, 64 in the manner described above. The arrangement in FIGURE 6 is particularly adaptable for this function since solid pellets or bars of aluminum may be placed in the crucible 64 without subjecting them to a temperature above the melting point while the iron is being melted and/or treated in the ladle 50 of the separate induction heated furnace 52. This is possible because the furnaces 52, 76 are separately controllable. Manifestly the temperature of the furnace 76 may be raised if desired after pouring of the metal from the ladle 50 has started. It will also be evi-

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dent that once the crucible 64 is filled to the level of the head 88 the head may also serve to keep any bars of aluminum placed therein submerged in the iron until melted. Furthermore the induction heating acts to keep the molten iron in motion to assure good mixing of the aluminum therewith.

The thermodynamic considerations concerned with the equilibrium of carbon and oxygen in a molten iron bath have heretofore been investigated by others. The controlling reaction representing the equilibrium of carbon and oxygen is given by the equation:



Moreover, the equilibrium constant K' of the above reaction in the low concentration ranges of carbon and oxygen is attained by experimental data reported by Chipman et al. in the Transactions of the A.S.M. 1941 and is expressed as follows in a relationship of the partial pressure of CO and the percentage concentration of both C and O in the melt:

$$K' = \frac{p_{\text{CO}}}{[\% \text{O}][\% \text{C}]} = 459$$

Referring to FIGURE 2, the graphs there shown are based upon the above thermodynamic considerations and curve C is plotted using only experimental data. These curves provide a means of determining with reasonable accuracy the sufficiency of oxygen in a given melt for equilibrium conditions and the reduction in carbon content of a melt possible from a given level thereof by the use of the procedures described above involving the formation and removal of CO from the melt.

Thus the curves in FIGURE 2 show the relationship between carbon and oxygen contents at 2800° F. at various pressures. Curves A, B and D are based on theoretical calculations and curve C upon actual experimental data. Curve A shows the relative concentration of oxygen and carbon in equilibrium in an iron-rich bath at one atmosphere of pressure. Curve B shows the reduction in concentration of oxygen and carbon in equilibrium when the bath is exposed to 0.1 atmosphere of pressure. Curve C shows the extent of improvement in carbon reduction possible when the molten bath is exposed to a pressure ranging from 5×10^{-6} to 5×10^{-2} millimeters of mercury, as obtained by experimental data, and curve D shows the results obtainable at a pressure of 0.01 atmosphere. The variations between curves C and D are due to thermodynamic factors.

From these curves it will be seen, for example, that an iron melt containing approximately 0.045% carbon would at one atmosphere of pressure have an equilibrium oxygen content of 0.0485%. Moreover, that if such melt is exposed in the manner described above to a lower pressure, for example 0.1 atmosphere, there would result as shown by curve B a lower equilibrium value for C and O. The reduction in each will follow the above equation $\frac{1}{2}\text{O}_2 + \text{C} \rightleftharpoons \text{CO}$; i.e., some of the soluble C and soluble O will combine in the course of treatment of the melt to produce CO at the lower pressures. From curve D it will be evident that an equilibrium condition can be attained at a pressure of 0.01 atmosphere, whereby the carbon content is reducible to 0.011%.

The graph in FIGURE 3 is based upon experimental test data obtained with test bars of a wrought iron aluminum alloy containing 6% by weight of aluminum and varying amounts of carbon after a one-hour anneal at 1500° F. It shows the changes effected in tensile strength and elongation for carbon contents of between 0.005% and 0.12%.

The graph in FIGURE 4 shows the Fe-Al-C diagram for iron-aluminum alloys containing 6% aluminum, and varying amounts of carbon as obtained from metallurgical samples. From this graph it will be evident that by the proper amounts of carbon it is possible to obtain

alloys operable over a wide range of temperature while maintaining a substantially wholly ferritic condition.

The following examples are illustrative of the application of the features of our invention and are not intended to place a limitation upon its scope.

Example 1.—A heat of about 2800 lbs. was prepared in an electric furnace in the following manner: 2500 lbs. plain carbon steel scrap containing 0.5% carbon was partially melted and 60 lbs. of lime (CaO) was added to the partially melted steel so as to produce a good basic oxidizing slag effective to remove phosphorous and sulphur impurities. When all of the scrap was melted 270 lbs. of iron ore (Fe_2O_3) was added.

The function of the iron ore was to aid in reducing the carbon content of the bath. The melt, with its slag blanket, was then treated with oxygen for five minutes by blowing oxygen into the bath from a suitable external source through a $\frac{1}{2}$ " lance. The temperature of the bath at this time was 2880° F. The effect of this treatment was to reduce the carbon content of the melt to 0.03%.

The oxidizing slag blanket was then slacked off and the bath again lanced with oxygen for three more minutes while raising its temperature to between 2900 and 2950° F. Electrolytic manganese in amount of about 5 lbs. was then added to the bath along with a reducing slag mixture composed of fresh lime, fluospar and cryolite, and granular aluminum. Sufficient slag mixture was added to cover the bath. The slag mixture was fluxed within four minutes without the use of any electric power. The reducing slag serves to remove excess oxides and oxygen.

The reducing slag blanket was then slacked off and the heat then tapped off into a ladle preheated to a temperature of about 1000° F. within six minutes after the reducing slag was added to the bath.

Prior to transferring the melt to the ladle, sufficient primary (pure) aluminum in an amount of about 6.67% by weight of the melt was placed in the ladle and preheated (but not melted) in the ladle. Also following tapping of the heat a small amount (about 0.02%) of calcium-silicon alloy was added to the ladle and the melt stirred with a furnace test spoon to assure a uniform composition of the metal.

The melt was now teemed into a sixteen-inch round corrugated mold through a $2\frac{1}{4}$ " nozzle. The mold was clean, uncoated, and warm before pouring. A clay hot top was placed into position on the mold with asbestos rope used at the junction to prevent any leaks. Before pouring was started about one pound of crushed cryolite was added to the bottom of the mold. A sixteen-inch round ingot weighing 2450 lbs. was produced in this operation, plus excess scrap butt of 500 lbs.

The ingot was cooled in the mold to room temperature before stripping.

Example 2.—Fifteen pounds of Armco iron containing 0.012% to 0.015% carbon by weight was melted in a magnesium oxide (MgO) lined crucible at a temperature of about 2900° F. The charge was covered with a slag blanket made up of a 50 gram 1-to-1 mixture of limestone (CaCO_3) and fluospar (CaF_2). The charge was fully melted in about 45 minutes and was then superheated under its slag blanket to 3000° F. to assure sufficient heat for the subsequent addition of aluminum. The melt was then deoxidized by the addition of 0.02% calcium silicon (CaSi) alloy. Aluminum pig in amount to produce a 6% iron aluminum alloy was then pushed in unmelted form under the blanket of slag and melted down in this manner. The bath was then stirred with a low-carbon steel or Armco iron rod. The temperature of the bath was then increased to 3100° F., after which the slag blanket was removed and the melt immediately poured into a $2\frac{1}{4}$ " octagonal shell mold made from a mixture of molding sand and phenolic resin binder.

The riser of the mold was covered with "Sil-O-Cel" refractory heat insulating material and the mold was then permitted to cool to room temperature before stripping the alloy therefrom.

Example 3.—Forty-five hundred grams of commercial Armco iron containing about 0.012% carbon was melted in a magnesium oxide lined crucible under vacuum in a Stokes vacuum induction unit, as shown in FIGURE 5.

After the charge was fully melted and was further heated by induction for about five minutes, a sample of the bath was taken and showed the presence of 0.005% carbon by weight. The melt was then heated to 3100° F. and 0.30 gram of graphite added. This increased the carbon content of the melt to 0.021% carbon by weight. Fifteen to 20 grams of iron ore in the form of Fe_2O_3 was then added to the melt to provide additional oxygen to the melt.

The vacuum chamber was then pumped down to a vacuum of better than 100 microns of Hg (100 μ) and while thus subjected to vacuum was poured as a stream from the narrow pouring lip of the crucible into a 6" diameter mold 18" to 24" below the same. The mold had a central raised hump such that the molten metal stream could impinge thereon and splash into the mold, thus breaking up the stream and facilitating the degassing action. The metal in the mold was then permitted to cool to room temperature while still subjected to vacuum. A sample of the metal showed the presence of 0.006% carbon.

Example 4.—Twenty-two hundred fifty grams of Armco iron was melted under a blanket of argon gas in a Stokes vacuum induction unit. After the charge was fully melted and was further heated by induction for about five minutes a sample of the bath was taken and showed the presence of 0.007% carbon by weight. The melt was then heated to 3100° F. and 0.30 gram of graphite added. This increased the carbon content of the melt to 0.135% carbon by weight. The melt was then saturated with oxygen by lancing the same with oxygen for 30 seconds at a pressure of 10 p.s.i. A sample taken of the melt at this time showed the presence of 0.0121% carbon.

The vacuum chamber was then pumped down to a vacuum of better than 500 microns (500 μ). A sample taken at this time of the melt showed 0.0068% carbon. The melt, while still subjected to vacuum, was then stream poured and splashed into a mold as in Example No. 3, during which continued degassing of gaseous oxides occurred. The metal was permitted to cool in the mold while under vacuum. A final sample showed the carbon content to be 0.0036%.

Example 5.—794.75 lbs. of Armco iron containing 0.013% carbon was melted in an induction heating furnace using a magnesium oxide lining and under a vacuum equivalent to a pressure of 20 microns of mercury. The temperature of the bath was about 2850° F. Four to 5 lbs. of mill scale (Fe_2O_3) was added to provide additional oxygen to the melt to facilitate a further reduction in the carbon content by "carbon boil." The melt was maintained under vacuum for about 30 minutes to accomplish this result. A sample of the iron was then checked and analyzed at 0.003% carbon.

The bath was then optionally treated to deoxidize the same by the addition of .02% CaSi, after which 55.25 lbs. of solid aluminum pig of commercial purity (99.9% pure) was added to the molten iron and stirred in by induction mixing. During this procedure the melt remained under vacuum. The temperature of the melt was then raised to 2950 to 3000° F., and then poured into 3" thick 10" x 14" steel tapered molds.

In Examples 3 and 4 the addition of graphite was for the sole purpose of raising the carbon content of the steel melt to a substantial amount or to above the critical for the ductile iron-aluminum alloy and to establish the vacuum stream treatment as a procedure for reducing the

carbon content of the melt. Such carbon addition would not be made in commercial practice.

From the above description of our invention it will be evident that we have provided a novel procedure for conditioning an iron or steel melt for combining with aluminum to produce ductile iron-aluminum alloys and processing for making the aluminum additions. It will be understood that while stream dispersing of the steel melt while subjected to vacuum is especially effective for reducing the carbon content thereof prior to making the aluminum addition that the application of vacuum to a melt alone has given good results.

It will be understood that various changes and modifications in the above-described procedures and apparatus will suggest themselves to those skilled in this art without departing from the spirit and interest of our invention. All such changes and modifications coming within the scope of the appended claims and equivalents thereof are therefore contemplated.

We claim:

1. The process of preparing ductile iron-aluminum alloys comprising directing a stream of molten iron having a carbon content above about 0.03% and up to about 0.2% by weight from a source thereof to a receptacle in which said molten iron is to be collected, said molten iron containing soluble carbon and oxygen, subjecting said stream of molten iron to a vacuum equivalent to a pressure of less than about $\frac{1}{10}$ of an atmosphere and dispersing said stream while subject to said vacuum to reduce the ferrostatic pressure thereon and produce a stream of droplets of molten iron increasing the exposed area of said stream to said vacuum to thereby induce the formation of gaseous oxides of carbon from said soluble carbon and oxygen in said stream, continuing the application of said vacuum to remove said gaseous oxides from said stream and reduce the carbon content of the molten iron collected in said receptacle to an amount below 0.03% by weight, introducing solid aluminum into the receptacle in a manner such that the aluminum is brought into contact with the substantially degassed stream of molten iron beneath the same, and introducing said aluminum in amount to produce an iron-aluminum alloy containing between about 3 to 12% by weight of aluminum, said alloy being ductile.

2. The process of preparing ductile iron-aluminum alloys comprising directing molten iron having a carbon content above about 0.03% and up to about 0.2% by weight through a restriction to form a flowing stream thereof, said molten iron containing soluble carbon and oxygen, subjecting said stream upon its discharge from said restriction to a vacuum equivalent to a pressure of less than about $\frac{1}{10}$ of an atmosphere to disintegrate the stream into molten droplets of iron and increase the exposed area of said stream to said vacuum, whereby to induce the formation of gaseous oxides of carbon from said soluble carbon and oxygen in said stream, continuing the application of said vacuum upon said stream to remove said gaseous oxides therefrom and reduce the carbon content of the molten iron to an amount below 0.03% by weight, feeding solid aluminum to said stream of molten droplets or iron at the base of said stream and at a rate in accordance with the rate of discharge of the molten iron from said restriction, and feeding said aluminum in amount to produce an iron-aluminum alloy containing between about 3 to 12% by weight of aluminum, said alloy being ductile.

3. The process of preparing ductile iron-aluminum alloys comprising directing a stream of molten iron having a carbon above about 0.03% and up to about 0.2% by weight from a source thereof to a receptacle in which said molten iron is to be collected, said molten iron containing soluble carbon oxygen, subjecting said stream of molten iron to a vacuum equivalent to a pressure of less than about $\frac{1}{10}$ of an atmosphere, impinging

said stream upon a protuberance arranged in the path thereof in said receptacle to break up the said stream into molten droplets of iron thereby reducing the ferrostatic pressure upon the molten iron of said stream and increasing the exposed area of said stream to said vacuum whereby to induce the formation of gaseous oxides of carbon from said soluble carbon and oxygen of said stream and continuing the application of said vacuum to remove said gaseous oxides from said stream and reduce the carbon content of the molten iron collected in said receptacle to an amount below 0.03% by weight and introducing solid aluminum into said receptacle in a manner that the aluminum is brought into contact with the substantially degassed stream of molten droplets of iron beneath the same, and aluminum being in amount to make a ductile iron-aluminum alloy containing about 3 to 12% by weight of aluminum.

4. The process of preparing ductile iron-aluminum alloys comprising directing a stream of molten iron having a carbon content above about 0.03% and up to about 0.2% by weight from a source thereof to a point of collection, said molten iron containing soluble carbon and sufficient soluble oxygen to combine as gaseous oxides of carbon with substantially all of said soluble carbon, inducing the formation of said gaseous oxides of carbon by subjecting said stream of molten iron to a vacuum equivalent to a pressure of less than about $\frac{1}{10}$ of an atmosphere, and after subjecting said stream to said vacuum forcibly disintegrating said stream to one of droplets of molten iron to increase the area of said stream exposed to said vacuum, continuing the application of said vacuum to remove said gaseous oxides of carbon from said stream and to reduce the carbon content of said molten iron at said point of collection to an amount below 0.03% by weight and introducing solid aluminum into said molten iron at the point of collection in a manner that the aluminum is brought into contact with the substantially degassed stream of droplets of iron beneath the same, said aluminum being in amount to produce a ductile iron-aluminum alloy containing between 3 to 12% by weight of aluminum.

5. The process of preparing ductile iron-aluminum alloys comprising melting by induction heating a charge of iron having a carbon content above 0.2% and up to about 1% by weight and containing soluble carbon and oxygen to combine with the soluble carbon subjecting said charge to a vacuum equivalent to a pressure of less than about $\frac{1}{10}$ of an atmosphere while agitating the same by induction to evolve gaseous oxides of carbon from the soluble carbon and the oxygen of said melt, then directing a stream of said melt to a point of collection while still subjecting said stream to vacuum and prior to reaching said point of collection and while still subject to the action of said vacuum forcibly acting upon said stream to disperse said stream into droplets of molten iron whereby to induce the formation of further gaseous oxides of carbon from further soluble carbon and the oxygen in said stream of droplets and to effect removal of said gaseous oxides of carbon therefrom whereby the carbon content of said molten iron at said point of collection is below 0.03% by weight and introducing solid aluminum into said molten iron at the point of collection in a manner that the aluminum is brought into contact with the substantially degassed stream of droplets of iron beneath the same, said aluminum being in amount to produce a ductile iron-aluminum alloy containing between about 3 to 12% by weight of aluminum.

6. The process of preparing ductile iron-aluminum alloys comprising subjecting a mass of iron having a carbon content above 0.2% and up to about 1% by weight and containing soluble carbon and sufficient oxygen to combine with the soluble carbon to melting under a protective blanket at a temperature sufficiently high to effect a reaction between the soluble carbon and the

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oxygen and the evolution of gaseous oxides of carbon from the melt, then directing a moving stream of the molten iron as thus treated into a collection receptacle and during said movement forcibly dispersing said stream into droplets of molten iron and subjecting said dispersed stream to a vacuum corresponding to a pressure less than about $\frac{1}{40}$ of an atmosphere whereby to reduce the carbon content of the molten iron in said receptacle to below 0.03% by weight and introducing solid aluminum into the molten iron at the point of collection in a manner that the aluminum is brought into contact with the substantially degassed stream of droplets of iron beneath the same, said aluminum being in amount to produce a ductile iron-aluminum alloy containing between about 3 to 12% by weight of aluminum.

7. The process as claimed in claim 6, including lancing the iron melt with oxygen while under said protective blanket.

8. The process of making ductile iron-aluminum alloys comprising directing a stream of molten iron having a carbon content above about 0.03% and up to about 0.2% by weight from a source thereof to a receptacle in which said molten iron is to be collected, said molten iron containing soluble carbon and oxygen, delivering to said receptacle prior to receiving said molten iron a quantity of aluminum in solid form in amount to produce an iron-aluminum alloy having between about 3% to 12% by weight of aluminum, mixing said solid aluminum with said molten iron to melt said aluminum and distribute the same through said iron, and prior to mixing said aluminum with said molten iron dispersing said stream to produce a stream of droplets of molten iron and subjecting said dispersed stream to a vacuum equivalent to a pressure of less than about $\frac{1}{40}$ of an atmosphere whereby to induce the formation of gaseous oxides of carbon from the soluble carbon and oxygen of said stream and its removal therefrom.

9. The process as claimed in claim 8 wherein the aluminum is in wire form and is fed into the dispersed stream of molten iron at the base thereof at a substantially constant rate in accordance with the rate of flow of the molten iron to said receptacle.

10. The process as in claim 8 wherein the aluminum is in the form of pellets which are fed into the dispersed

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stream of molten iron at the base thereof at a substantially constant rate in accordance with the rate of flow of the molten iron to said receptacle.

11. The process as claimed in claim 1 wherein said aluminum is in amount to produce an alloy having between $3\frac{1}{2}\%$ to 8% by weight of aluminum.

12. The process as claimed in claim 5 where there is an excess of oxygen in the melt.

13. The process as claimed in claim 5 where there is sufficient oxygen in the melt to combine with the soluble carbon and part of the oxygen is supplied by lancing the melt therewith.

14. The process as claimed in claim 6 where the oxygen is sufficient to combine with the soluble carbon and a part of the oxygen is present as soluble oxygen and part as an oxide.

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