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IRON AND STEEL PRODUCTS AND PROCESS OF PRODUCING THE SAME

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This invention relates to the production of iron and steel products comprising in their composition elements which, if present under ordinary conditions of iron and steel manufacture, would deleteriously affect the quality or even render commercially valueless iron and steel products containing them, but which, when contained in the novel products of the present invention produced by the novel process of the present invention, not only do not have any deleterious effect upon the products but in many cases improve the qualities of the products for certain uses.

The invention relates particularly to avoiding the deleterious effects of the presence, in iron and steel products, of elements of the group commonly to be found in iron ores, such as phosphorus, sulfur, silicon and titanium, when such ores are reduced and the resultant iron is manufactured into iron and steel products by the processes commonly employed, and at the same time to take advantage of the beneficial effects of the presence of one or more of these elements in iron and steel products, when introduced under certain conditions which are provided for by the practice of the present invention.

In the manufacture of iron and steel articles by the processes generally employed at the present time, which involve the reduction of the iron ore in the blast furnace and subsequent operations of melting and refining the ore in the open hearth furnace, Bessemer converter or electric furnace, it has long been known that, if the elements above referred to, or compounds thereof, are present in appreciable quantities during the aforesaid stages in the production of iron and steel articles, these elements, and particularly phosphorus, silicon and titanium, tend to reduce to the elemental form and tend to go into combination with the iron, either in the form of solutions of the elements in the iron or in the form of chemical compounds thereof, with the result that they materially impair or alter the physical characteristics of the finished product. If sulfur be present in the ore in appreciable quantities or if it be present in the coke used in the reduction, or in the fluxes, or in the refractory linings of any of the furnaces, it forms with the iron a eutectic mixture, known as the iron-iron sulfide eutectic, which has a freezing point lower than that of the pure iron or steel. When, therefore the manufacture of an iron or steel product involves a melting stage, then, upon solidification of the iron or steel product, this iron-iron sulfide eutectic mixture, which freezes last, will be crowded out of the matrix of the material and will be forced to segregate around the grain boundaries of the material, thus weakening the final product and, moreover, because of its low melting point, causing the condition known as "hot shortness" to exist in the iron or steel.

The property of iron and steel commonly termed "hot shortness" is usually understood to mean a lack of ductility or workability at ordinary forging, hot rolling or otherwise deforming temperatures and is apparently caused by the distintegration or softening of the iron sulfide constituent under the heat of the forging, rolling or other deforming operation. To avoid this property in the final product, it is necessary, in normal steel-making practice, to supply a considerable amount of metallic manganese in the steel bath in order to form a manganese sulfide compound with the residual sulfur and thus prevent the formation of the iron-iron sulfide eutectic. The manganese sulfide thus formed to a great extent enters into the slag but a considerable proportion of it remains mechanically entrapped in the steel where, having a freezing point higher than that of the iron and steel and thus solidifying first, it is not segregated or driven to the grain boundaries of the steel but rather remains as individual inclusions and thus does not materially affect any of the physical characteristics of the finished product.

When phosphorus, silicon and titanium are present in appreciable quantities in steel which has been molten and which has been maintained at temperatures sufficiently high and under conditions sufficiently reducing to reduce the compounds of phosphorus, silicon and titanium which are found in the ores or in other materials with which the ores are associated during reduction, these elements, when thus reduced, tend to go into solution in the iron and also, in certain cases, to form chemical compounds which cause embrittlement and lack of strength in the finished product. Phosphorus, in particular, creates in the finished product a condition known as "cold shortness," which is evidenced by a lack of ductility in the finished product at ordinary temperatures and which prevents the cold rolling or cold working of iron and steel containing appreciable amounts of phosphorus.

There is no simple treatment which will effect the immobilizing of phosphorus, silicon or titanium such as the manganese treatment for sulfur. It has been found in practice, therefore, that the phosphorus content in finished steel,

which has gone through a melting stage in its manufacture, must be maintained below 0.10% of phosphorus. Silicon and titanium can be tolerated in finished materials to a considerably greater degree but their presence as solid solution constituents or as chemical compounds or as eutectics is not desirable since it does not contribute to uniformity and dependability in a finished steel product.

Not only does the present invention make possible the production of iron and steel products comprising, in their composition, the elements hereinabove specifically mentioned, without any deleterious effect upon the quality or commercial value of the iron and steel products by reason of the presence of these elements, but it has also been found that other elements, which are sometimes associated with iron ores and which, if chemically associated with the finished iron or steel product, tend to impair or change the physical characteristics thereof, may also be rendered inocuous by the practice of the present invention.

An important advantage of the present invention is that it makes possible in the manufacture of iron and steel products, and particularly in continuous processes to this end, the utilization of iron ores which, by reason of the impurities contained therein which are not readily removable or which tend to cause trouble during the reduction or fabrication of the iron, have heretofore been considered unsuitable or uneconomical for commercial use. Among the ores of iron or steel which have been found to have commercial utility when employed in the manufacture of iron or steel products embodying and made by the process of the present invention, are the ilmenite beach sand ores and the other ores high in titanium which have not been used up to the present time to any great extent because of their high titanium content; the high sulfur ores, particularly those containing pyrrhotite, and the high phosphorus ores.

Other objects and important advantages of the invention will appear from the following description of the practical application of the invention to the manufacture of iron and steel products.

In the practice of the present invention it has been found that if iron ore be reduced by means of a direct reduction process such as described in the co-pending application of Herman A. Brassert, Serial No. 323,076, filed March 9, 1940, Manufacture of metal products, by which a finely divided ore, either mixed with finely divided carbon or without having carbon added thereto, is supported upon a perforated hearth and independently agitated while a reducing gas is passed through the hearth and through the ore supported thereon; or in the co-pending application of James C. Hartley, Serial No. 338,560, filed June 3, 1940, Process of and apparatus for facilitating and controlling chemical reactions and physical treatments, by which a finely divided ore, supported on a hearth having inclined jet orifices, is both agitated and reduced by passing a heated reducing gas through said orifices with sufficient force to effect the agitation of the ore and its movement over the hearth; or in the co-pending application of James C. Hartley, Serial No. 339,095, filed June 6, 1940, Process of reducing metallic oxides, by which a finely divided concentrated ore, either coated or impregnated with a finely divided carbon, is substantially completely reduced by raising it to the reduction temperature and effecting an agitation thereof. The reduced ore is then further concentrated by reducing its temperature to the magnetic range and effecting a magnetic concentration thereof and the concentrated reduced ore is then subjected to a further reduction treatment by means of a gaseous reducing agent which effects both the agitation and the reduction thereof, and if, as outlined in said copending applications, the reduction temperatures be maintained below the temperatures at which the oxides or compounds of the elements hereinabove mentioned, excepting sulfur, reduce, then these elements will not be able to go into solution or to form chemical compounds or eutectics with the iron or steel and will remain in their original oxidic or chemical compound form and will exist in the finished product, after it has been consolidated and mechanically deformed, as individual and discrete inclusions which will not adversely affect the properties of the finished product, except insofar as their bulk as inclusions, if left in in too large amounts, might do so. Furthermore, it has been found that, since these materials have not entered into solution or into combination with the iron, there will be no particular tendency for them to segregate or to form agglomerates within the mass of the iron and thus no tendency to cause non-uniformity or discontinuity within the finished product.

In the case of sulfur, which will normally exist during and after the reduction operation as iron sulfide, this constituent having never become molten cannot form the iron-iron sulfide eutectic hereinabove referred to and cannot be forced to segregate around the grain boundaries and will, therefore, exist as separate inclusions of iron sulfide, more or less uniformly dispersed within the matrix of the finished product. Under these conditions the iron sulfide, instead of causing "hot shortness" or brittleness, will impart to the finished product free machining properties without otherwise seriously impairing its physical characteristics. It has been found in practice that sulfur contents of slightly over 0.5% can be tolerated in a finished steel bar produced in accordance with the practice of the present invention without in any way impairing the hot working characteristics of the material and without noticeably impairing the physical strength or ductility of the product.

As an illustration, sponge iron which, when reduced by the process particularly described in the application of James C. Hartley, Serial No. 338,560, hereinabove identified, still contained 0.5% of sulfur, was compacted and sintered after the direct reduction and then hot forged at 2200° F. until it was reduced 90% in area. There was no formation of any forging cracks or other evidence of "hot shortness" as a result of this procedure.

In the case of inclusions of titanium oxide, it has been found in practice that as much as 1.8% of titanium oxide in iron and steel products produced in accordance with the present invention has no markedly deleterious effect upon the physical characteristics. Silica up to 2%, as inclusions in iron and steel products made in accordance with the practice of the present invention, does not appear to impair materially the physical characteristics of the product. The tolerance of phosphorus in iron and steel products made in accordance with the present invention has been increased from 0.10%, the maximum allowable in iron and steel products that go through a molten stage, to 1.25%.

Not only does the present invention contemplate the manufacture of iron and steel products in which some or all of the elements hereinabove referred to are found in the ores from which the iron is reduced and are retained as inclusions in the finished products, but, when ores of very high purity are to be utilized in the production of iron and steel products and when material having free machining characteristics is desired as an end product, the invention contemplates the addition to the ore prior to reduction, or to the product of the reduction operation immediately subsequent to the reduction, definite amounts of iron sulfide or other sulfur compound in order to provide for inclusions of iron sulfide in the finished product uniformly dispersed throughout the matrix to give the product the desired free machining characteristics.

The expression "directly reducing," used in the specification and claims, applies to that type of reduction operation in which the metal oxide and the reducing agent are brought directly into reactive relation to each other at a reactive temperature that serves merely to bring about the reduction of the oxide to the metallic state, without the incidental reactions which take place in the blast furnace where melting of both the metal oxide and the most of the gangue constituents is an incident of the smelting of the ore.

What is claimed as new is:

1. An iron or steel product which, both in its unfinished and in its finished condition, has, as an inclusion within the matrices of grains thereof and in noneutectic relation to the iron, a compound, other than manganese sulfide, of an element of a group consisting of sulfur, phosphorus, titanium, silicon.

2. An iron or steel product which, both in its unfinished and in its finished condition, has, as an inclusion within the matrices of grains thereof and in noneutectic relation to the iron, a compound of an element of a group consisting of sulfur, phosphorus, titanium, silicon, said compound being of the type which would impair the physical characteristics of the product is produced by a process involving melting of the iron.

3. A free machining iron or steel product having, as an inclusion within the matrices of grains thereof and in non-eutectic relation to the iron, iron sulfide.

4. An iron or steel product which, both in its unfinished and in its finished condition, is substantially free from the iron-iron sulfide eutectic but containing, as an inclusion, iron sulfide.

5. An iron or steel product which, both in its unfinished and in its finished condition, contains substantial quantities of iron sulfide in the form of a uniformly dispersed inclusion not segregated at the grain boundaries.

6. An iron or steel product which, both in its unfinished and in its finished condition, is substantially free from titanium in solution in the iron but containing, as an inclusion, titanium oxide.

7. An iron or steel product which, both in its unfinished and in its finished condition, has phosphorus as a constituent but not in solid solution therewith.

8. An iron or steel product which, both in its unfinished and in its finished condition, has phosphorus as a constituent but free from Fe_3P.

9. An iron or steel product which, both in its unfinished and in its finished condition, has phosphorus as a constituent but free from the iron-iron phosphide eutectic.

10. The process of producing an iron or steel product having, as an inclusion within the matrices of grains thereof and in non-eutectic relation to the iron, a compound of an element of a group consisting of sulfur, phosphorus, titanium, silicon, which consists in directly reducing a finely divided iron ore containing a compound of one of the aforementioned elements and compacting the reduced powder and deforming it into the desired product, all at a temperature below the temperature of fusion of the iron or of said compound.

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