METHODS, SYSTEMS AND DEVICES FOR MAKING COLD BONDED AGGLOMERATES

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ABSTRACT

There are provided methods, systems and processes for forming cold bonded agglomerates in the form of pellets, briquettes or compacts from iron oxide materials, such as iron ore concentrates. The cold bonded agglomerates have sufficient strength and durability to be handled and shipped without significant damage. Forming the iron ore concentrate product into agglomerates facilitates the shipment and handling of the product and places the product in a form that is suitable for use by a wider variety of iron making customer facilities. There are also provided methods, systems and devices for handling greenballs as they cure, and before they have gained sufficient strength for significant handling, stockpiling or shipping.
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CROSS REFERENCE TO RELATED APPLICATION

0001. The present application claims the benefit of U.S. Provisional Patent Application No. 61/442,777 filed Feb. 14, 2011, which is incorporated herein by reference in its entirety.

BACKGROUND

0002. It is customary in the mining industry to agglomerate ore or pelletize finely ground mineral ore concentrate, such as, for example, iron oxide concentrates, so as to further facilitate the handling and shipping of the ore. Agglomerate forms can include pellets, briquettes, and sinter.

0003. In the beneficiation of some ores, such as taconite, hematite, specularite, magnetite and the like, for subsequent use in iron-making, it is necessary to reduce the ore as it occurs in nature to a particulate form, so as to release the ore particles from the particles of silica and other gangue-like constituents using screening techniques to remove large particles which are recycled for further grinding. After being reduced, the particles of ore are separated from the silica and gangue using, for example, magnetic separation techniques to produce a higher grade ore, and the resulting beneficiated ore includes a higher percentage of iron than as found in nature. Typically, an ore that has been beneficiated is of a size that passes through a 100 mesh (0.149 mm) screen. The so processed mineral ore is known as a “concentrate.”

0004. The division of the ore into particles, though necessary for the beneficiation or concentrating steps, gives rise to other challenges in the further use of the product, because the relatively fine ore particles are not suitable for use in a typical blast furnace in this form. For use in a typical blast furnace, the ore should be in relatively larger particles, so as to be capable of packing loosely to allow the furnace blast to pass upwardly therethrough during the smelting operation.

0005. To address this challenge, a variety of techniques have been proposed for producing agglomerates of particulate iron ore that are in a better form for use in a blast furnace or other iron-making furnace. A challenge associated with the formation of agglomerates, however, is that such agglomerates must have sufficient strength to avoid significant breakage during handling between the agglomerating process and the ultimate iron-making furnace to which the agglomerates are charged. One approach that has been employed is to mix water with finely divided ore and then form balls or compacts of the ore. For example, the finely divided ore may be introduced with eight percent to twelve percent of water into a revolving tube set at a slight gradient. The particles of ore rolling upon themselves agglomerate into spherical masses ranging in size from one-eighth inch up to one inch, or even larger. By suitable control of the moisture, speed of rotation and other factors, the production of spherical or nearly spherical balls or compacts may be accomplished at relatively low cost. Such balls can be made to have sufficient wet strength to permit a limited amount of handling; however, they are not suitable for shipping or for use directly in the blast furnace because they are relatively friable when they dry out.

0006. Such balls of ore particles can be heated to a temperature just below the melting temperature of the ore to frit the ore particles together and form hard, strong pellets capable of shipment, storage and handling and sufficiently strong for use in a blast furnace. This can be done, for example, in a combustion chamber furnace in which fuel is burned in external combustion chambers and the hot furnace gases are blown through the pelletizing chamber. However, the balls of ore particles, prior to being sintered, must be handled, and often times transported, to the location where sintering is done. Thus, much attention has been given to development of processes for importing sufficient durability to the balls of ore particles so that they will remain intact during such handling and shipment prior to sintering.

0007. One approach that has been employed to allow handling and shipment of balls of iron ore particles is to mix the particulate iron ore with various binders and to form the mixtures into iron ore agglomerates. Such processes are commonly referred to as “cold agglomeration” processes. In a cold agglomeration process, green balls are made by first mixing the particulate iron ore with a curing agent, and then forming the mixture into agglomerates or compacts, which can form durable “cold pellets” after completion of curing. Such cold pellets must have sufficient strength that they do not break or crack as they are handled and shipped to a location where they can be sintered or otherwise further processed.

0008. Two standard tests are used to measure the strength of pellets whether the pellets are green pellets or fired pellets. These tests are the “drop” test and the “compression” test. The drop test requires dropping a random sampling of pellets a distance, usually about 18 inches or less, a number of times until the pellets crack. The number of drops to crack each pellet is recorded and averaged.

0009. Compression strength is measured by compressing or applying pressure to a random sampling of pellets until the pellets crumble or otherwise break. The pounds of force required to crush the pellets is recorded and averaged. These two tests are used to measure the strength of both cold pellets and fired pellets. The drop and compressive test measurements are important because pellets, proceeding through a balling drum, subsequent conveyor belts and other handling devices and processes, experience frequent drops as well as compressive forces from the weight of other pellets travelling on top of them.

0010. Challenges that are encountered in cold agglomeration processes include the need to produce cold pellets that have sufficient compression strength and impact strength after curing for handling and shipment prior to sintering, and also the need for systems and devices to handle the agglomerates during the early stages of curing and before they have gained sufficient strength for conventional stockpiling, storing and shipment. Such handling often can be done only after complete curing, which typically takes several hours or days. While the agglomerates gradually gain strength over the curing time, they are very fragile during the early stages of curing, and must be handled with great care. In addition, during the early stages of curing, the curing agent in the agglomerates tends to cause adjacent agglomerates to become attached to one another if they are in static contact with one another during this time, particularly if they are pressed together. A wide variety of alternative proposals have been made to address these challenges, including alternative pelletizing steps and conditions, alternative pellet formulations and alternative curing devices, methods and systems. Each of these has disadvantages, however. There remains a need for advancements in the development of processes,
devices and systems for making cold bonded agglomerates that include minerals such as iron oxides. The present application addresses this need.

SUMMARY

[0011] The present application provides methods, systems and devices for making cold bonded agglomerates that include iron ore and a binder, which cold bonded agglomerates have sufficient durability and strength to withstand handling and shipment, including shipment for great distances, prior to sintering, without significant crushing, breaking or cracking.

[0012] In one aspect, the application provides a method for making a cold bonded agglomerate including iron oxide that includes: (1) mixing a particulate iron oxide material with a hydraulic bonding agent to provide a solids mixture; (2) introducing the solids mixture into a first rotating pelletizer; (3) spraying water onto the solids mixture as it resides in the first rotating pelletizer; (4) recovering generally spherical green balls from the first rotating pelletizer; (5) passing the greenballs through a size classifier to provide an oversized fraction, and undersize fraction and an on size fraction; and (6) subjecting the on size fraction to conditions effective for the greenballs to cure as individual cold bonded agglomerates. In one embodiment, the method also includes conveying the undersize fraction into the first rotating pelletizer or into a second rotating pelletizer. In another embodiment, the method also includes delivering the oversized fraction to a shredder to convert the oversized fraction to a shredded material and introducing the shredded material into the first rotating pelletizer, the second rotating pelletizer or a third rotating pelletizer.

[0013] In one embodiment, the particulate iron oxide material comprises iron ore concentrate. In another embodiment, the iron oxide material comprises a filter cake from a wet high intensity magnetic separation system. In yet another embodiment, the hydraulic bonding agent comprises a member selected from the group consisting of ordinary Portland cement (OPC) and ground Portland cement clinker (GPCC). In still another embodiment, the solids mixture further comprises an additive selected from the group consisting of wheat starch, corn starch binder, bentonite, organic polymer binder, burnt lime, hydrated lime, quick lime, slack lime, active MgO lime, and burnt MgO lime.

[0014] The water is preferably sprayed onto the solids mixture as it resides in the first rotating pelletizer in an amount effective to promote curing of the hydraulic bonding agent. In one embodiment, the first rotating pelletizer is selected from the group consisting of a balling drum and a balling disk. In another embodiment, the curing device is operable to prevent exposure of the greenballs to greater than a one pound of compressive force from any direction. In yet another embodiment, the greenballs are allowed to cure in the curing device for at least 8 hours.

[0015] In another aspect, the present application provides a method for making a cold bonded agglomerate feed material including iron oxide that includes: (1) feeding into a curing device a plurality of generally spherical greenballs; the greenballs comprising an iron oxide material, a hydraulic bonding agent and water; wherein the curing device defines a greenball flow path and is configured to allow movement of the greenballs through the flow path for a period of time sufficient for the greenballs to become at least partially cured; (2) passing a flow stream of the greenballs along the flow path to produce partially cured cold bonded agglomerates; and (3) discharging the partially cured cold bonded agglomerates from the flow path. The flow path is configured to prevent the flow stream from having a vertical depth of more than about ten inches at any single point of the flow path. In another embodiment, the curing device also includes a discharge opening for discharging the partially cured cold bonded agglomerates from the flow path, and can optionally include a conveyor configured to receive the partially cured cold bonded agglomerates from the flow path and convey the partially cured cold bonded agglomerates to the discharge opening. In an embodiment including such a conveyor, the conveyor can be configured, for example, to prevent the partially cured cold bonded agglomerates conveyed thereon from having a vertical depth of more than about twenty inches at any single point of the conveyor. In another embodiment, the flow path extends from the inlet to the outlet.

[0016] In one manner of practicing this method, the period of time that a respective greenball resides in the flow path is at least about eight hours. In another embodiment, the period of time that a respective greenball resides in the flow path is at least about sixteen hours. In yet another embodiment, the flow stream of the greenballs provides for motion of the respective greenballs in the flow stream relative to other greenballs in the flow stream, and the relative motion is not interrupted for any period of more than eight hours between said feeding of the respective greenballs and said discharging of the respective partially cured cold bonded agglomerates. In still another embodiment, the greenballs in the flow path are not subjected to greater than one pound of compressive force from any direction. The greenballs fed into the curing device can be formed, for example, in an agglomerating device selected from the group consisting of a disk pelletizer, a drum pelletizer, a compactor, and a high pressure briquetter.

[0017] In another aspect, the present application provides a curing device for producing partially cured cold bonded agglomerates. The curing device includes an inlet for receiving a charge of generally spherical greenballs; an outlet for discharging partially cured cold bonded agglomerates; and a channel defining a flow path for said greenballs. The inlet is configured to prevent a dropping of the greenballs any distance greater than ten inches. In other embodiments, the inlet is configured to prevent a dropping of the greenballs any distance greater than eight inches, greater than six inches or greater than four inches. The outlet is positioned at a location lower than the inlet. The channel has a floor oriented at a slope of at least two degrees measured from horizontal upon which the greenballs travel along the flow path from the inlet to the outlet. The channel is configured to prevent the flow stream from having a vertical depth of more than about ten inches, or in another embodiment more than about eight inches, at any single point of the flow path.

[0018] In one embodiment, the flow path of the curing device comprises a non-linear flow path. In another embodiment, the device further comprises a system for delivering moisture to the flow path. The moisture delivery system can be, for example, a humidifier system or a water delivery system effective to deliver a spray of water onto the greenballs in at least one region of the flow path. In another embodiment,
the water delivery system is operable to pass steam through the flow path to subject the greenballs to a steam treatment.

In one embodiment, the curing device comprises a bin having a cylindrical outer wall, a central column and a stationary helically shaped floor affixed to the outer wall and the central column, the floor having a downward slope of not less than two degrees measured from horizontal, said curing device allowing gentle movement of the greenballs through the curing device in a spiral trajectory from the inlet to the outlet at a controlled mass flow rate such that each of the greenballs resides in the curing device for at least eight hours.

In another embodiment, the curing device comprises a bin having an outer wall that defines an internal chamber, and multiple sloped floors positioned within the chamber in a generally stacked relationship with a space therebetween, each one of the sloped floors sloping in a direction that is generally opposite of the slope of the floor or floors adjacent to it; wherein the lower end of each floor is separated from the outer wall and defines a space between the floor and the outer wall near the lower end of the floor to allow greenballs supported by said floor to drop to the next lower floor through said space; wherein the flow path is defined by the outer wall and the multiple sloped floors and allows gentle movement of the greenballs through the curing device in a generally zig-zag pattern from the inlet to the outlet at a controlled mass flow rate such that each of the greenballs resides in the curing device for at least eight hours.

These and other aspects of the inventive methods, systems and devices are described further below.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**[0022]** FIG. 1 is a diagrammatic view in cross section of one curing device embodiment of the present application.

**[0023]** FIG. 2 is a diagrammatic top plan view of another curing device embodiment of the present application.

**[0024]** FIG. 3 is a diagrammatic view in cross section of the embodiment depicted in FIG. 2 along line 3-3.

**[0025]** FIG. 4 is a diagrammatic view in cross section of the embodiment depicted in FIG. 2 along line 4-4.

**[0026]** FIG. 5 is a diagrammatic view in cross section of another curing device embodiment of the present application.

**DETAILED DESCRIPTION**

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the specific embodiments, including embodiments illustrated in the figures, and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any such alterations and further modifications in the described devices, systems, processes and methods, and such further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the present application relates.

The present application provides methods, processes, devices and systems to make cold bonded agglomerates from particulate iron oxide materials such as particulate iron ore concentrate. The present application provides a relatively uncomplicated process for producing cold pellets having good cold and hot strength. This application relates to cold bonded pellets which contain a significant amount of an iron particulate material, and which have sufficient strength to be handled and shipped prior to sintering.

In one aspect, there is provided a method for making iron ore pellets in the form of cold bonded agglomerates from iron ore and an inorganic or mineral cement that is admixed with the iron ore before pelletization. The pellets are made from “iron particulate material,” which, in addition to referring to iron ore concentrate or other iron ore particles as such, for example hematite powder, sinter feed fines, sinter fines, and ore concentrate fines, also includes a wide variety of particulate materials derived from iron smelting processes which contain significant amounts of recoverable ferrous values, such as electric arc furnace (EAF) dust, basic oxygen furnace (BOF) dust, mill scale, steelmaking sludge, rolling scales, blast furnace dust and the like. While the term “iron ore” is used herein in connection with the descriptions of various method, system and device embodiments, it is to be understood that other iron particulate materials, or mixtures thereof, are also contemplated. The major portion of the iron ore should be about 200 mesh or smaller, and preferably between about 200 mesh and 325 mesh in order to provide good pellet strength. In one embodiment, the iron ore starting material is at least 80% minus 200 mesh. In another embodiment the iron ore starting material is at least 80% minus 270 mesh. In yet another embodiment, the iron ore is at least 80% minus 325 mesh. The iron content of the iron ore is preferably at least about 60%.

The methods described herein can employ a variety of conventional inorganic or mineral bonding agent, such as, for example, ordinary Portland Cement (OPC™), finely ground Portland Cement clinker (“GPCC™”), hydrated lime otherwise known as calcium hydroxide, calcined lime (“CaO”) otherwise known as active lime or burnt lime, the same forms of lime as aforementioned except rather than being made from limestone only, those made from either dolomite or from blends of dolomite and limestone; or bentonite. In one embodiment, the iron ore is mixed with a hydraulic bonding agent and optionally with other additives, before it is mixed to provide a solids mixture suitable for introduction into a pelletizing device. Examples of suitable hydraulic bonding agents include ordinary Portland Cement (OPC™) and finely ground Portland Cement clinker (“GPCC™”). Examples of other additives that can be included in the solids mixture include one or more organic binders, such as, for example, poly(acrylamide), poly(methacrylamide, carboxymethyl cellulose, hydroxyethyl cellulose, carboxyhydroxyethyl cellulose, poly(ethylene oxide), guar gum, wheat starch, wheat gluten, wheat starch, corn starch, blends thereof and others. For example, one suitable commercially available wheat starch that can be used is Benebind WS9520, which is sold by Spectra Applied Technologies (Clayton, Wis.). One advantage of the use of organic binders in iron ore pelletizing operations over the use of bentonite, for example, is that organic binders do not increase the silica content of pellets and they improve the thermal shock resistance of the pellets. Organic binders burn during pellet firing operations and cause an increase in the porosity of the pellets.

While the starting materials used to prepare the solids mixture can be substantially dry, it is also contemplated that the iron ore can be provided in the form of a filter cake produced by a wet high intensity magnetic separation system, which will have some level of moisture entrained therein. Such a mixture is within the meaning of the term “solids mixture” herein. In one embodiment, additional water is not added to the solids mixture during this preliminary mixing phase; it being understood that additional water will be added.
in a later phase of the method when the solids mixture is mechanically formed into green briquettes or pellets. [0032] In one manner of practicing the method, the iron ore starting material is a filter cake produced in an iron ore upgrading device referred to as a Rev3™ magnetic separator as described in pending U.S. patent application Ser. No. 12/913,373, filed Oct. 27, 2010; an iron ore upgrading device referred to as a Rev3.1™ separator as described in pending U.S. Provisional Patent Application No. 61/477,590, filed Apr. 20, 2011; or an iron ore upgrading device referred to as a MagWheel™ separator as described in U.S. Utility Patent No. 8,886,913, issued Feb. 15, 2011; each of which is commonly owned with the present patent application, and which is hereby incorporated by reference herein.

[0033] For example, when the Rev3™ separator, Rev3.1™ separator, MagWheel™ separator or other wet iron ore upgrading process is used, the final iron ore concentrate slurry product from such processes can be pumped to a thickening hydroseparator to reduce excess water and possibly reject additional ultrafine gangue particles, and then can be dewatered using vacuum disk filters of the disk variety which produce a filter cake with a water content typically 9.5% plus or minus 1.0 percentage point. In place of the vacuum disk filters, the final iron ore concentrate slurry product from these processes can be pumped to a Hydrocyclone which reduces excess water and rejects additional ultrafine gangue particles prior to dewatering. The overflow or underflow of Hydrocyclone can be passed through a vibrating dewatering screen. The underflow from the vibrating dewatering screen can be recirculated to a Hydrocyclone where the underflow is passed through the vibrating dewatering screen to produce filter cake. The filter cake from either the dewatering screen circuit or vacuum disk filters can be used as the iron ore starting material for making greenballs as described herein.

[0034] The iron ore concentrate product produced by the above-described processes can be formed into agglomerates useful for shipping and handling, such as, for example, agglomerates having the form of briquettes, pellets or compacts. A method of producing cold bonded agglomerates includes mixing the particulate iron ore material with a hydraulic bonding agent and optionally a desired amount of other additives, such as, for example one or more binders, conveying the resulting mixture to a balling device, where water is added and the mixture is mechanically processed into green briquettes or pellets (referred to herein as greenballs), and then curing the greenballs.

[0035] More particularly, a filter cake as described above or other iron ore concentrate is fed to a mixer along with a hydraulic bonding agent where they are thoroughly mixed prior to being fed into a rotating pelletizer. The mixing can be performed in a batch mode or a continuous mode. A wide variety of intensive mixers are commercially available that can be employed to achieve mixing of the starting materials. In one preferred embodiment, the mixing is done in a continuous mode. Examples of intensive mixers that are suitable for use in a continuous mode of this method are cylindrical mixers that rotate about a horizontal axis with an input at a first end, a rotating central shaft with paddles that move the input materials along the axis from the first end toward the second end, and a bottom exit that discharges the mixed materials at the second end. Such mixers are commercially available, for example, from Muller; Scott and Littleford Day, Inc. One particularly suitable mixer is Littleford Day intensive mixer model KM 600 50 HP. As will readily be appreciated by a person of ordinary skill in the art, multiple mixers can be used in parallel to increase the rate at which greenballs are produced.

[0036] In one embodiment, the iron ore and hydraulic bonding agent starting materials are charged into the mixer in proportions such that the solids mixture includes from about 75 to about 85% iron ore and from about 15 to about 25% hydraulic bonding agent, by weight. In one embodiment the iron ore is a filter cake produced in a Rev3.1™ separator as described above. In another embodiment, the filter cake has an iron content of at least about 60%. In another embodiment the hydraulic bonding agent is OPC. In yet another embodiment, the solids mixture comprises from about 78 to about 82% of the filter cake and from about 18 to about 22% OPC, by weight.

[0037] In another embodiment, the starting materials are charged into the mixer in proportions such that the solids mixture includes from about 75 to about 85% iron ore, from about 15 to about 25% hydraulic bonding agent and from about 0.100 to about 2.000% of an organic binder, by weight. In one embodiment the iron ore is a filter cake produced in a Rev3.1™ separator as described above. In another embodiment the filter cake has an iron content of at least about 60%. In another embodiment the hydraulic bonding agent is OPC. In yet another embodiment, the organic binder is selected from the group consisting of wheat gluten, wheat starch and corn starch. In still another embodiment, the solids mixture comprises from about 78 to about 82% of the filter cake, from about 18 to about 22% OPC and from about 0.100 to about 1.000% of the organic binder, by weight.

[0038] The amount of iron ore contained in the pellets is dependant on the iron content of the iron ore and the amount of the binder(s) mixed with the iron ore. In one embodiment, the amount of iron ore contained in the pellets is, on average, at least about 60% by weight.

[0039] The solids mixture discharged from the mixer is conveyed to a pelletizing device to produce generally spherical greenballs. In one embodiment, the pelletizing device is a rotary pelletizer such as, for example, a balling disk or a balling drum. In other aspects, the present application also contemplates the production of greenballs using alternative pelletizers, such as, for example, high pressure briquetters or presses. The pelletizing can be performed in a batch mode or a continuous mode. In an embodiment utilizing a rotary pelletizer, it is preferred that the rotary pelletizer be operated in a continuous mode, with a solids mixture conveyor system delivering the solids mixture to one or more rotary pelletizers at rates that can be determined, set, and optionally adjusted, by an operator.

[0040] In the rotary pelletizer, the iron ore is further mixed with the hydraulic bonding agent and the optional additives of the solids mixture, and water is also added to the solids mixture in the rotary pelletizer to provide a wetted mixture. The wetted mixture is formed into greenballs (also referred to herein as “green pellets”) in the rotary pelletizer by rolling. In an embodiment in which it is desired to include an organic binder in the greenball, the organic binder can in some cases be added by dissolving the organic binder in the water to be sprayed onto the solids mixture in the rotary pelletizer. In this regard, some organic binders used in iron ore pelletizing operations are soluble in water, and therefore can be dissolved in an aqueous solution which is sprayed onto the solids mixture in the balling drum(s) or disk(s) or optionally prior to entering the balling drum(s) or disk(s).
The water is preferably delivered to the solids mixture in the rotary pelletizer slowly so that the solids mixture does not become mud-like, which is detrimental to the formation of greenballs. The amount of water to be delivered to the solids mixture and the rate at which the water is delivered are preferably less than would result in over-wetting as discussed above, but at least sufficient to hydrate the hydraulic binding agent in the greenballs being formed. Otherwise, the properties of the cold bonded agglomerate ultimately produced, for example compressive strength and impact strength, are adversely affected. In addition, if insufficient water is provided, the cold bonded agglomerate product might contain at least some more or less loose and uncremented powder, which is not desirable.

In one embodiment, the rotary pelletizer is a balling drum. Balling drums are apparatuses well known in the art that include one or more long cylinders that are inclined and rotated. The addition of water to a solids mixture conveyed into the cylinder(s) can be achieved using conventional plumbing components positioned within the cylinder(s). The wetted mixture in a drum is simultaneously rotated about the balling drum’s circumference and rolled in a downward direction along the axis of the cylinder through the drum. In this manner the wetted mixture is rolled and tumbled together to form generally spherical shaped pellets. As the pellets grow in size and weight they travel down the incline of the drum and pass through the exit of the drum at its lower end at which point they can be dropped onto another conveyor.

Inside a balling drum, different factors influence the mechanisms of union of the mineral ore concentrate. These factors include the moisture content of the wetted mixture, the shape and average size of the iron ore particles, the size distribution of iron ore particles and the proportions at which the iron ore, the hydraulic bonding agent and the water are mixed, to name a few. Other properties of the iron ore that influence the pelletizing operation include the iron ore’s wet-ability and chemical characteristics. The characteristics of the equipment used, such as its size and speed of rotation, can effect the efficiency of the pelletizing operation. A person operating the balling drum can adjust the speed of rotation, the rate at which water is delivered and other parameters as needed.

The formation of agglomerates begins with the interfacial forces which have a cohesive effect between particles of the iron ore and the hydraulic bonding agent, which is affected by the water present. Numerous particles adhere to one another and form small pellets. The continued rolling of the small pellets within the balling drum causes more particles to come into contact with one another and adhere to each other. These forces cause the union of particles in small pellets to grow in much the same manner as a snowball grows as it is rolled. As is well known to a person of ordinary skill in the art, a balling disk operates in much the same manner, but the rolling effect is achieved on the top surface of a rotating disk rather than on the inside surface of a rotating cylinder. An example of a balling disk that is suitable for use in this method is a 25-foot diameter balling disk that is commercially available from Metso Minerals. Another example is a 16-foot diameter balling disk that is commercially available from Mars, which is owned by Woodward, Inc.

The discharge from the rotary pelletizer operation will typically include greenballs of varying sizes, and also may include some non-agglomerated particles. This pelletizer discharge is preferably passed through a size classifier, such as, for example, a screening device to separate the pelletizer discharge into three size fractions, namely, an undersize fraction, an oversize fraction and an on size fraction. This separation can be achieved, for example, using conventional roll screens and conveyors well known in the art and commercially available. For example, in one embodiment, roll screens are used to close the balling disk or balling drum circuit so that only on size greenballs are discharged from the circuit. In one embodiment, the on size fraction has a size range of from about 1 mm to about 10 mm, more preferably from about 2 mm to about 8 mm, still more preferably from about 4 to about 6 mm and most preferably from about 4.5 to about 5.5 mm. Cured agglomerates made using greenballs of these embodiments are referred to as “micropellets,” and comprise an excellent sinter plant feed. Such micropellets have sufficiently strong compressive strength and impact strength after curing to be suitable for being handled and shipped, for example, using rail cars, for subsequent sintering, where the high temperatures of sintering will give the micropellets further strength needed for subsequent reduction in a blast furnace.

In other embodiments, cold bonded agglomerates made as described herein can be fed directly into a blast furnace. In embodiments for making agglomerates for this use, the on size fraction has a size range of from about 10 mm to about 50 mm, more preferably from about 15 mm to about 40 mm, still more preferably from about 20 to about 30 mm and most preferably from about 25 mm to about 30 mm. In other embodiments, any ranges within the above-mentioned size ranges may be selected for production of cured agglomerates for particular end uses. In other embodiments in which the cured agglomerates are being made for other uses, other size ranges within a range of from about 1 mm to about 50 mm can be collected as the on size fraction.

In one embodiment, the greenballs in the oversize fraction are shredded and the shredded material optionally can be returned to the same or a different balling disk or drum, for example, either by mixing the shredded material into the solids mixture during the mixing phase or by return of the shredded material directly into a balling disk or drum. The undersize fraction discharged from a balling disk or a balling drum is also returned to the same or a different disk or drum, for example, either by mixing into the solids mixture during the mixing phase or by return directly into a balling disk or drum.

A wide variety of conventional components, such as, for example, conveyors, mixers, pelletizers, water delivery systems, control systems and the like can be used in the method described above and are within the skill of a person of ordinary skill in the art in view of the present specification. In addition, various process parameters and features can be modified without departing from the invention described herein. For example, modification of the process to incorporate additional size screening steps, size reduction steps, mixing steps, water delivery steps, agglomeration steps, and the like are modifications contemplated by the present application.

The on size greenball fraction is conveyed to a curing device where the curing of the greenballs proceeds to a point where they can be handled with less risk of breakage. While the curing device and the curing method is described herein with reference to the on size greenball fraction as described above, it is to be understood that the curing device and the curing method can also be used to cure other generally
spherical greenballs or green pellets produced by other methods and having other compositional makeup. The curing device described herein is operable to move a flow stream of greenballs in a relatively gentle manner through a humid environment as the curing progresses with the greenballs in the flow path being protected from excessive compressive force and from being dropped one or more times in a manner that would cause an excessive impact prior to having gained sufficient strength to withstand such force or impact. As used herein, the term “excessive” as it relates to the compressive force or dropping impact is intended to refer to a force or impact at which the greenball would become broken or cracked. In one embodiment, the flow path is configured to prevent the flow stream from having a vertical depth of more than about ten inches at any single point of the flow path. In another embodiment, the vertical depth is limited to no more than eight inches at any single point of the flow path. This can be accomplished, for example, by confining the flow path within a channel that, in addition to a floor on which the greenballs rest, includes a ceiling that prevents the flow of greenballs from exceeding a desired depth.

[0053] The curing device into which the greenballs are charged is configured to store at least eight hours of production volume in a manner whereby the greenballs are not exposed to compressive forces that will damage the greenballs in the early stages of curing while they are still in a soft/fragile condition. In one embodiment, channel 130 is configured to prevent the flow stream from having a vertical depth of more than about ten inches at any single point of the flow path. It is expected that the curing process will have reached a point in about eight hours whereby the agglomerates have gained sufficient strength to support the weight of more than twelve inches of balls stacked thereupon.

[0054] In another embodiment, depicted in FIGS. 2-4, greenball curing device 200 includes a bin 205 having a cylindrical outer wall 260, a central column 270 and a stationary helically shaped floor 240 affixed to the outer wall and the central column. In one embodiment, the helically shaped floor 240 has a downward slope that is slightly steeper than the natural angle of repose of a pile of the freshly made greenballs. In one embodiment, the floor has a downward slope of at least about 2 degrees measured from horizontal. In other embodiments, the floor can have a different slope, as can be determined by one skilled in the art of material handling and pelletization. Newly made greenballs 201 are fed into curing device 200 through a top opening in the bin at inlet 210. When putting a curing device into operation initially, the bin must be filled with pre-cured hardened balls with a small headspace near the top of the bin to accept new fresh uncured greenballs. The curing device also includes an outlet opening 220 near the bottom of the bin. While outlet 220 is shown in FIG. 2 as being in a bottom surface of curing device 200, in other embodiments, outlet 220 is formed as an opening through side wall 260 near the bottom of device 200. The outlet mass flow rate of partially cured cold bonded agglomerates 202 is controlled by any number of devices easily selected by one skilled in the art of material handling such as a vibratory feeder, a table feeder, or a rotary valve. For simplicity, FIG. 3 simply shows conveyors to feed greenballs 201 and recover discharged partially cured cold bonded agglomerates 202. By regulating the outlet rate, the residence time for greenballs in the curing device can be maintained so as to provide at least the eight hour cure time prior to removal of the cured greenball from the storage bin and subsequent storage in conventional conical piles. The curing device is configured to prevent the uncured greenballs from being exposed to excessive compressive forces prior to gaining sufficient strength to withstand such forces.

[0055] As will be appreciated by a person of ordinary skill in the art, the curing device may be designed and constructed in a variety of geometric configurations so long as the gentle treatment of the fragile greenballs is attained and the minimum residence time of at least 8 hours maintained. For example, in another embodiment the curing device can have a rectangular or square cross sectional shape with a height, width and length and multiple floors with a slight downward slope upon which the greenballs may be fed onto the top floor through an opening in the rectangular bin providing a minimal drop from for example a conveyor delivering the freshly made greenballs to the top of the floor of the rectangular bin.

[0056] In FIG. 3, curing device 300 includes a bin 305 having an outer wall 360, to which are connected a plurality of sloped floors 340. Each of sloped floors 340 slopes in a direction that is generally opposite of the slope of the floor.
above in and the floor below it. The lower end 345 of each floor 340 is separated from outer wall 360 and defines a space 346 between the floor 340 and outer wall 360. Greenballs and/or partially cured cold bonded agglomerates (not shown in this drawing) supported by a given floor 340 drop through space 346 to the next lower floor. The flow path 335 in this embodiment is defined by outer wall 360 and floors 340. In addition, a ceiling can define the upper boundary of flow path 335 to prevent the flow stream from having a vertical depth of more than about ten inches at any single point of the flow path. Greenballs are allowed to gently move through device 300 in a generally zig-zag pattern from inlet 310 to outlet 320.

[0057] In one embodiment, each floor in device 300 can have a vibratory feeder (not shown) that upon activation of vibration at a frequency and amplitude sufficient to cause movement of the 6-12 inch bed of greenballs accumulated thereupon such vibratory action would effectuate the movement of the greenballs down the slope of the floor to the point where the full width of layer of greenballs would gently fall a short distance of say six inches to eight inches in vertical height to the next floor below which would be designed to be sloping downward in the opposite direction of the floor above it. This downward zig-zag floor arrangement would gently lower the greenball mass downward from floor to floor until the greenballs exit the bin onto a conveyor or feeder that would move the greenballs to a conventional conical storage pile, a conventional storage silo or bin, a rail car, a railroad container, a truck box or a vessel hold or other container or storage pile where the balance of the 28 day curing time may elapse and the greenballs have sufficient strength to withstand the handling attendant to such handling and storage methods.

[0058] The balls discharged from curing device 100, 200, 300 through outlet 120, 220, 320 are in a partially-cured condition. In one embodiment, the curing device contains the greenballs for a period of time sufficient to allow the greenballs to cure to a point whereby the hardened (partially-cured) balls have sufficient compressive strength to be stored in a conical pile for complete curing, which typically occurs over a multiple day period, typically one to four weeks, during which time the balls achieve full strength. After curing is complete (or sufficiently complete) the agglomerates have sufficient strength and durability for shipment and handling. In this regard, it has been determined that within 24 hours of formation, the greenballs made as described above will have achieved about 70% of their final strength, and within about 72 hours the cold bonded agglomerates will have achieved 100% of final strength, which has been determined to be a compressive strength of at least 50 pounds and an impact strength whereby about 90% of the cold bonded agglomerates survive a 50-foot drop. In view of the above, in one embodiment, the greenballs move through the flow path of curing device 100, 200, 300 at a rate whereby the time period that elapses from the greenballs' entrance at inlet 110, 210, 310 to the exit of the partially-cured greenballs from the outlet 120, 220, 320 is at least eight hours. In another embodiment, the greenballs' residence time in the curing device is at least 16 hours. In yet another embodiment, the residence time is at least about 24 hours.

[0059] The flow path within the curing device is preferably maintained at a high humidity during operation. In one embodiment, the flow path is maintained at 100% relative humidity at ambient temperature (provided that ambient temperature is above freezing). In another embodiment, the temperature is at least 60° F. In yet another embodiment, the temperature is at least 70° F. To prevent the greenballs from sticking to each other in the device due to the hydration reaction, it is desirable that the greenballs in the curing device move through the flow path without any significant period of stoppage. As used herein, the phrase "significant period of stoppage" refers to a time period that would cause the greenballs and/or partially cured cold bonded agglomerates to stick together to a degree that continued movement through the flow path is restricted. In one embodiment, the flow of balls through the curing device is not interrupted for more than eight hours. In other embodiments, the flow is not interrupted for more than 6 hours, or for more than 4 hours, respectively. In some embodiments, the curing device includes a water delivery system to spray water onto the load of greenballs at a given point along the flow path. The water delivery system may be configured to spray a light mist of water over the greenballs passing through the flow path. In another embodiment, the curing device is configured to treat the balls in the flow path with steam. Steam treatment would be expected to increase the rate of cure of the greenballs. As a result, an embodiment that includes steam treatment can be operated to pass the greenballs through the device in a shorter period of time, and still attain sufficient strength for subsequent handling and shipment.

[0061] If operation of the pelletization system that is producing the greenballs being charged to the curing device is interrupted, such as due to regular maintenance or breakdown, and therefore ceases to produce greenballs, the charge of the raw pellets stops. As a result, the top level of the charged material inside the curing device continues to fall. If operation of the pelletization system resumes at a time after the last-charged greenballs have moved a considerable distance along the flow path from the inlet, any newly-charged greenballs would be likely to break as they moved through the flow path at a rate greater than the desired rate, and therefore would be likely to become broken or cracked as they contacted various walls of the flow path. Moreover, even if some or all of the greenballs were to withstand such impacts, such greenballs might not be present in the curing device for a sufficient period of time to reach a desired level of curing before exiting the curing device through the outlet.

[0062] To prevent this problem from occurring, after the latest-charged greenballs start to move away from the inlet, already-cured cold bonded agglomerates can be fed into the inlet to operate as space-fillers in place of greenballs. The already-cured agglomerates will therefore maintain positions in the flow stream that would otherwise have been taken by greenballs, thereby preventing the rapid movement of new greenballs that are introduced through inlet after pelletization resumes. The already-cured agglomerates charged to the inlet can be conveyed directly from the outlet of the curing device, or can be fed to the inlet from a stockpile of already-cured agglomerates. After the pelletization operation resumes, the charge of the already-cured agglomerates is stopped and the charge of greenballs is resumed. If an occasion occurs in which the pelletization system is idled for a relatively long time, for example, due to periodic repair or maintenance, the charge of the cured agglomerated ore can be continued until the charged matter inside the curing device is completely replaced by the already-cured agglomerates, at which time the movement of the agglomerates can be stopped, as the already-cured agglomerates are not susceptible to sticking to one another as are greenballs.
[0063] After the initial cure in the above-described curing device, the partially-cured agglomerates may be placed into shipment containers including truck boxes, shipment containers, supersacks, rail cars or vessel holds where they may be dosed with additional water to control fugitive dust and advantageously strengthen the cementaceous bonds by providing adequate water to the ball during the second stage cure, which is typically complete in about 28 days. The balls will gain most of the ultimate strength in less than one week, with smaller gains thereafter so that after only a few days of curing some more rigorous handling may be undertaken.

[0064] In another embodiment of the application the greenballs are made with a mixture recipe that is advantageously made with the end user iron or steel maker in mind. For example the green ball may include a carbon ingredient or specific fluxing agents in ratios that produce advantageous results with respect to reduction of the iron oxide and the formation of liquid iron and desulfurization of the resultant iron. The metallurgical properties related to the reactions desired in a blast furnace especially the performance in the cohesive zone of the blast furnace of the composite product is believed to be superior to ordinary iron oxide balls due to the high performance mixtures of fluxes and reducing agents that can be included in the greenball.

[0065] The foregoing embodiments achieve production of agglomerates in the form of a cold bonded agglomerate that has compressive strength and durability sufficient to withstand shipping and handling to customers located significant distances as much as several thousand miles away from the point where the filter cake is produced.

[0066] In another alternative embodiment, instead of providing a relatively dry solids mixture to a rotating pelletizer before adding water, a wet mixture is prepared prior to being fed into a rotary pelletizer. In this embodiment, a filter cake produced from the iron ore concentrates recovered by the methods and processes described herein is mixed with the following binders (concentration dosages based on weight as a percent of the overall mixture total weight): between 5% and 15% OPC (best dosage depending on compressive strength desired in the final agglomerate ball), between 0.5% and 1.5% wheat gluten binder (most advantageous dosage is 0.9% by weight wheat gluten binder), and between 5% and 15% water (most advantageous water dosage is 9.5% by weight). The wet mixture is intensively mixed using for example an intensive mixer such as the mixers manufactured by the Littleford Mixer company, and the wet mixture is subsequently fed to a balling device such as a pelletizing disk or pelletizing drum, preferably one that is equipped in a closed circuit with a roll screen using conveyor belts to transport the oversize balls to a shredder for re-feeding to the pelletizing unit and further to transport the undersize balls back to the pelletizing unit for increase in ball size, and further use of conveyors to transport the on-size wet ("green") balls to a curing and storage device.

[0067] While the invention has been illustrated and described in detail in the drawing and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiments have been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

1. A method for making a cold bonded agglomerate including iron oxide, comprising:

- mixing a particulate iron oxide material with a hydraulic bonding agent to provide a solids mixture;
- introducing the solids mixture into a first rotating pelletizer;
- spraying water onto the solids mixture as it resides in the first rotating pelletizer at a rate effective to cause the development of greenballs in the first rotating pelletizer;
- recovering generally spherical green balls from the first rotating pelletizer;
- passing the greenballs through a size classifier to provide an oversize fraction, and undersize fraction and an on size fraction; and
- subjecting the on size fraction to conditions effective for the greenballs to cure as individual cold bonded agglomerates.

2. The method in accordance with claim 1, further comprising conveying the undersize fraction into the first rotating pelletizer or into a second rotating pelletizer.

3. The method in accordance with claim 1 wherein the particulate iron oxide material comprises iron ore concentrate.

4. The method in accordance with claim 1 wherein the hydraulic bonding agent comprises a member selected from the group consisting of ordinary Portland cement (OPC) and ground Portland cement clinker (GPCC).

5. The method in accordance with claim 1 wherein the solids mixture further comprises an additive selected from the group consisting of wheat gluten binder, wheat starch, corn starch binder, bentonite, organic polymer binder, burnt lime, hydrated lime, quick lime, slack lime, active MgO lime, and burnt MgO lime.

6. The method in accordance with claim 1 wherein the water is sprayed in an amount effective to promote curing of the hydraulic bonding agent.

7. The method in accordance with claim 1 wherein the first rotating pelletizer is selected from the group consisting of a balling drum and a balling disk.

8. The method in accordance with claim 1, further comprising:

- delivering the oversize fraction to a shredder to convert the oversize fraction to a shredded material; and
- introducing the shredded material into the first rotating pelletizer, the second rotating pelletizer or a third rotating pelletizer.

9. The method in accordance with claim 1 wherein said subjecting comprises charging the on size fraction into a curing device in accordance with claim 21.

10. The method of claim 9 wherein the curing device is operable to prevent exposure of the greenballs to greater than a one pound of compressive force from any direction.

11. The method of claim 10 wherein the greenballs are allowed to cure in the curing device for at least 8 hours.

12. The method in accordance with claim 1 wherein the iron oxide material comprises a filter cake from a wet high intensity magnetic separation system.

13. A method for making a cold bonded agglomerate feed material including iron oxide, comprising:

- feeding into a curing device a plurality of generally spherical greenballs; the greenballs comprising an iron oxide material, a hydraulic bonding agent and water; wherein the curing device defines a greenball flow path and is configured to allow movement of the greenballs through the flow path for a period of time sufficient for the greenballs to become at least partially cured;
passing a flow stream of the greenballs along the flow path to produce partially cured cold bonded agglomerates; and

discharging the partially cured cold bonded agglomerates from the flow path;

wherein the flow path is configured to prevent the flow stream from having a vertical depth of more than about ten inches at any single point of the flow path.

14. The method in accordance with claim 13 wherein the curing device further includes a discharge opening for discharging the partially cured cold bonded agglomerates from the flow path, and a conveyor configured to receive the partially cured cold bonded agglomerates from the flow path and convey the partially cured cold bonded agglomerates to the discharge opening.

15. The method in accordance with claim 14 wherein the conveyor is configured to prevent the partially cured cold bonded agglomerates conveyed thereon from having a vertical depth of more than about twenty inches at any single point of the conveyor.

16. The method in accordance with claim 13 wherein the period of time that a respective greenball resides in the flow path is at least about eight hours.

17. The method in accordance with claim 13 wherein the period of time that a respective greenball resides in the flow path is at least about sixteen hours.

18. The method in accordance with claim 13 wherein the flow path extends from the inlet to the outlet.

19. The method in accordance with claim 13 wherein the flow stream of the greenballs provides for motion of the respective greenballs in the flow stream relative to other greenballs in the flow stream, and wherein the relative motion is not interrupted for any period of more than eight hours between said feeding of the respective greenballs and said discharging of the respective partially cured cold bonded agglomerates.

20. The method of claim 13 wherein, in the flow path, the greenballs are not subjected to greater than one pound of compressive force from any direction.

21. The method of claim 13, further comprising, before said feeding, forming greenballs in an agglomerating device selected from the group consisting of a disk pelletizer, a drum pelletizer, a compactor, and a high pressure briquetter.

22. A curing device for producing partially cured cold bonded agglomerates, comprising:

an inlet for receiving a charge of generally spherical greenballs, wherein the inlet is configured to prevent a dropping of the greenballs any distance greater than ten inches;

an outlet for discharging partially cured cold bonded agglomerates, the outlet positioned at a location lower than the inlet; and

a channel defining a flow path for said greenballs, the channel having a floor oriented at a slope of at least two degrees measured from horizontal upon which the greenballs travel along the flow path from the inlet to the outlet;

wherein the channel is configured to prevent the flow stream from having a vertical depth of more than about ten inches at any single point of the flow path.

23. The device in accordance with claim 22 wherein the flow path comprises a non-linear flow path.

24. The device in accordance with claim 22, further comprising a system for delivering moisture to the flow path.

25. The device in accordance with claim 24 wherein said system comprises a humidifier system.

26. The device in accordance with claim 24 wherein said system comprises a water delivery system effective to deliver a spray of water onto the greenballs in at least one region of the flow path.

27. The device in accordance with claim 22, wherein the curing device comprises a bin having a cylindrical outer wall, a central column and a stationary helically shaped floor affixed to the outer wall and the central column, the floor having a downward slope of not less than two degrees measured from horizontal, said curing device allowing gentle movement of the greenballs through the curing device in a spiral trajectory from the inlet to the outlet at a controlled mass flow rate such that each of the greenballs resides in the curing device for at least eight hours.

28. The device in accordance with claim 22, wherein the curing device comprises a bin having an outer wall that defines an internal chamber, and multiple sloped floors positioned within the chamber in a generally stacked relationship with a space therebetween, each one of the sloped floors sloping in a direction that is generally opposite of the slope of the floor or floors adjacent to it; wherein the lower end of each floor is separated from the outer wall and defines a space between the floor and the outer wall near the lower end of the floor to allow greenballs supported by said floor to drop to the next lower floor through said space; wherein the flow path is defined by the outer wall and the multiple sloped floors and allows gentle movement of the greenballs through the curing device in a generally zigzag pattern from the inlet to the outlet at a controlled mass flow rate such that each of the greenballs resides in the curing device for at least eight hours.

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