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METHOD OF STRENGTHENING IRON ORE AGGLOMERATES

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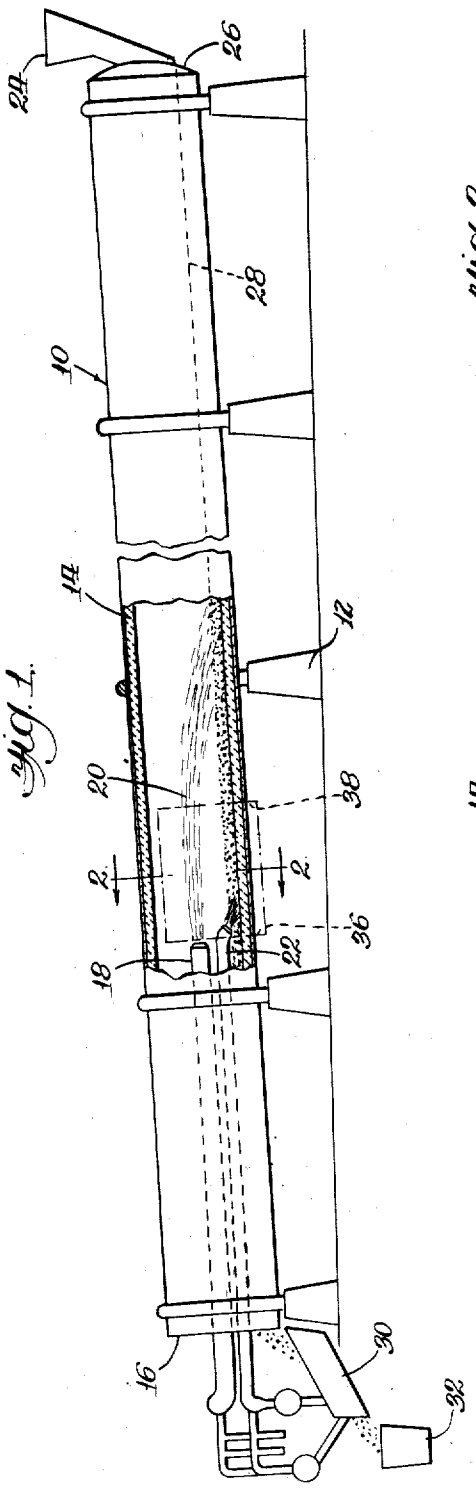


Fig. 1.

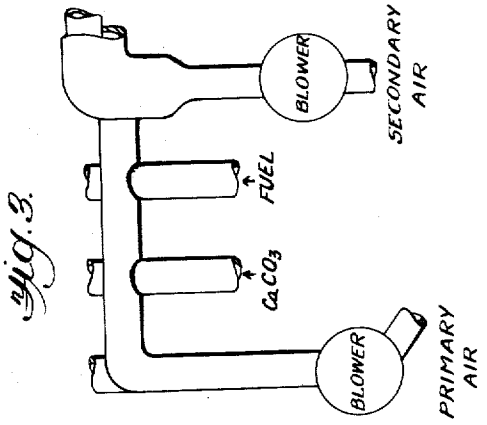


Fig. 3.

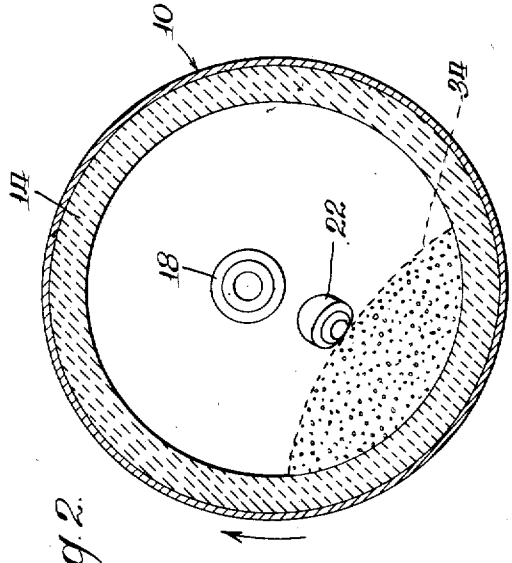


Fig. 2.

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METHOD OF STRENGTHENING IRON ORE AGGLOMERATES

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12 Claims. (Cl. 75—5)

This invention relates to a method of strengthening iron ore agglomerates. More particularly, it relates to treating the surface of taconite nodules during the final stage of their formation with a composition which forms with the nodule a eutectic which wil fuse into a strong bond and at a temperature just below the high temperature of the present nodulizing proces. The invention may be adapted to hardening the surface of taconite pellets and to any other agglomerate in which there are substantial quantities of iron oxides, including hematite (Fe_2O_3), on the surface of the agglomerate.

Applicants' process is particularly adapted to the nodulizing proces which has been developed at the Mesabi Range to agglomerate taconite iron ore because it can be inserted as a step in that process without altering the kiln and with practically no capital investment. However, as above indicated, it can be adapted to sintering, pelletizing and briquetting processes.

In nodulizing, a fine iron ore usually containing a binder or a flux or both is moving through a rotating kiln in a gradually rising temperature, and snowballs into a larger unit or agglomerate about the size of a walnut. As the nodules reach the desired size, they move past the burner nozzles into a cooling zone. The nodules are not of satisfactory strength, however. Between the product bin of the above-described process and the blast furnace, the nodules receive the same rough treatment that has always been given a hematite ore. They are moved by conveyors, picked up and dropped by shovels, and poured into piles from spouts 40 or 50 feet high. A high percentage of the nodules break, and the more they break, the more further handling tends to pulverize them. Taconite fines are useful in neither the blast furnace nor the open hearth. In the former, a substantial percentage is blown into the dust catcher, and in the latter, the fines will not sink through the slag.

It is essential that this defect in strength be cured for the taconite pellet or nodule has already proved its worth in competition with good hematite. Having more iron than the hematite and containing less oxygen, Fe_3O_4, (in taconite) against Fe_2O_3 (in hematite), less flux and less coke is required to reduce the iron oxide in the taconite than in the hematite. With coke breeze at twenty dollars a ton, it is readily seen that the use of taconite fines (their unavoidable condition at the end of the magnetic separation process) must not fail because of the inability to satisfactorily agglomerate.

The object of this invention is to strengthen the nodules, and other taconite agglomerates, by giving them a stronger surface. The composition of this improved surface must not be detrimental to blast furnace operation. Advantageously, the surface should be placed upon the nodule in the course of the agglomerating process. All of these ore-agglomerating processes increase the cost of the blast furnace raw material. At the present time, the additional cost of these processes does not impair the competitive character of the end product, firstly, because the competition of cheaper ores, such as hematite, is partly offset by additional transportation charges (from more distant fields), and the taconite nodules are substantially higher in iron content. Nevertheless, each additional step is costly and is practical only if it can be worked into an existing process without substantial additional cost.

The following is a detailed description of the invention furnished in conjunction with the drawings in which:

Fig. 1 is a diagrammatic view in side elevation of a form of apparatus particularly suitable for carrying out the present process, a portion of the wall of the apparatus being broken away to better illustrate the invention;

Fig. 2 is an enlarged sectional view taken on the line 2—2 of Fig. 1 looking in the direction of the arrows; and

Fig. 3 is an enlarged view showing the fuel and air-mixing portion of the apparatus of Fig. 1 and illustrating the manner in which the agglomerate-strengthening agent may be introduced into the apparatus in accordance with a preferred embodiment of the invention.

Referring to Fig. 1, applicants schematically illustrate a rotary kiln **10** as presently used in the nodulizing process at one plant in the Mesabi Range. This kiln is 350 feet long, 11½ feet in diameter, and is inclined at a slope of one-half inch per foot. It rests on piers such as **12**, and is rotated by means not shown. The kiln is lined with refractory brick **14**, the thickness of which increases toward the delivery end **16**. Extending inwardly of the delivery end of the kiln are burners. Applicants show a main burner **18** which is designed to direct a lazy flame **20** having a length of 50 to 75 feet axially of the kiln. Disposed beneath the burner **18** is an auxiliary burner **22** which is directed downwardly toward the wall of the kiln. The nozzle of this burner and the air pressure supplied to it produce a hard flame.

A charging chute **24** is disposed at the feed end **26** of the kiln and the charge moves downwardly along the dotted line **28**, immediately under the hard flame burner **22**, and ultimately through a cooling unit **30** to a hopper **32**. Referring to Fig. 2, the kiln **10** is rotating clockwise so that the charge tends to collect as illustrated between the dotted line **34** and the wall of he kiln. The particles tumble over one another and grow in size. The hard flame burner **22** is directed at an angle into this mass of tumbling nodules. The kiln is operated with a charge content of between 10 to 15 percent of its gross volume.

In operation, the nodules may be started by mixing seeds into the charge of taconite fines from the bin **24**. These seeds are particles that are substantially larger than the fines. The temperature of the hot gases leaving the feed end **26** of the kiln will be in the neighborhood of 500° F. In the course of the movement of the nodules down the kiln, the hot gases will heat the growing nodules. The rate of rotation of the kiln, the weight of charge fed to the kiln per unit of time, and the slope of the kiln are such that a nodule of a desired size will be obtained at the time of the sharp final heating under the hard flame **22**. It will be appreciated that skill in operation is of the utmost importance and that there is a considerable range in which the kiln's rotation and amount of charge introduced per unit of time may be varied, usually to compensate for variations in the chemical constitution of the charge. In the northern part of the Mesabi Range, the iron in the taconite is almost all magnetite, that is, Fe_3O_4. In the southern part of the field, the iron in the taconite is almost wholly hematite, that is, Fe_2O_3. The hematite is non-magnetic and the magnetite is magnetic, and since all of the processes presently developed rely upon magnetic separation, the present development in the Mesabi Range is taking place at the northern end of the field where primarily magnetite is encountered. For the pur-

poses of this invention, the magnetic quality of the iron compound is not important.

The foregoing description of the nodulizing process is to make clear that despite variations in technique and the chemical compositions in the charges, nodules reach a desired size at a point in the kiln immediately in advance of the burners. There is a space at this point for performing a surface operation on the nodules.

The first important feature in applicants' process therefore is to perform the surface-solidifying step at a point where further enlargement of the nodules is not desired. This occurs substantially adjacent the hard flame nozzle **22**. It is at this point that the temperature of the nodules no longer continues to rise. It is true that after the nodules have passed under this burner, their temperature is such, approximately 2400° F., that further tumbling, which occurs, may slightly increase their diameter. However, this is unavoidable unless the nodules are dropped immediately into a cooler, which also is undesirable.

The second important step in applicants' process is the selection of the bonds which will strengthen the surface of the agglomerates. The bonds were initially sought for and selected because the temperature at its hottest point in the nodulizing process is in the neighborhood of 2400° F. Applicants recognized that if a bond could be found which formed below this temperature and which was nevertheless a strong bond, a glaze or partial glaze could be put on the nodules. In U. S. Letters Patent 2,703,445, dated March 8, 1955, the applicant Veale disclosed a process for hardening the surface of briquettes containing a large amount of silica by means of depositing on the surface of the briquettes an oxide of calcium, or magnesium, or of calcium and magnesium. The temperature of the bricks was raised to 2000° F. or less and the surface bonds formed were silicates. It occurred to the applicants that they might improve the strength of the taconite nodules by utilizing this process because the surface of the taconite nodules is about 6–7% silica and if the spraying powder is limestone or dolomite, there is additional available silica. However, the quality of silica is definitely low and the formation of the bonds might be insufficient in number to materially glaze the surface of the taconite agglomerate.

In the course of experimenting, with spraying heated taconite agglomerates with powdered calcium carbonate ($CaCO_3$, limestone) or calcium-magnesium carbonates ($CaMg(CO_3)_2$, dolomite), it was discovered that a strong glaze was obtained at temperatures commencing at about 2300° F., usually in the neighborhood of 2400° F. It was at first assumed that this glaze was a silicate glaze, but there just did not seem to be sufficient silica present to account for it. Moreover, the coloring did not suggest a silicate glaze, but rather indicated that the iron oxide played some part of the glaze. The experiments proved conclusively that something was attained at a temperature around 2300° F. which was not there no matter how long the temperature was maintained below 2100° F.

The bonds obtained are calcium ferrites or calcium-magnesium ferrites and the reason for this is that the eutectic of calcium oxide, specifically Fe_2O_3, and of calcium-magnesium oxide and iron oxide is slightly below 2400° F. Additionally, applicants' nodule has calcium iron silicate bonds and magnesium oxide silicate bonds where the raw material is dolomitic limestone, which, however, are formed at lower temperatures as disclosed in the copending application.

The fusion temperature of calcium oxide (CaO) is in excess of 4000° F. The fusion temperature of iron oxide in the form Fe_2O_3 is in excess of 2400° F. The two, however, form a eutectic at approximately 1200° C. or 2192° F. (Journal of the American Ceramic Society, vol. 30, No. 11, part 2, page 24, Figure 46) to form calcium ferrite which has the formula $CaOFe_2O_3$. In the earliest,

simplest experiments performed by applicants, taconite nodules and pellets obtained from the three different companies developing these processes on the Mesabi Range, were immersed in a slurry of water and powdered limestone and then placed in an electric furnace. As the temperature passed about 1500° F. (the water having earlier vaporized) the calcium carbonate ($CaCO_3$) in the limestone converted to lime (CaO) the carbon dioxide (CO_2) being released. As the temperature continued to rise, the calcium with or without iron formed a limited number of silicates, either calcium silicate or calcium iron silicate. Also, the iron oxide in the taconite which had been in the form Fe_3O_4 converted to Fe_2O_3 by picking up additional oxygen. As the temperature passed above the eutectic of iron oxide (Fe_2O_3) and calcium oxide (CaO), a large number of calcium ferrite bonds were formed. Cracking the pellet shows a discolorization extending as much as 1/16 of an inch into the surface of the pellet.

Equally satisfactory results were obtained by the use of dolomite. Dolomite contains magnesium carbonates as well as calcium carbonates and the bonds formed are calcium-magnesium ferrite bonds and magnesium iron silicate bonds, the latter forming at a lower temperature. The applicant has not been able to find in the literature the eutectic of calcium oxide, magnesium oxide and iron oxide, but it is reasonably apparent from the hardened nodule produced that it is below 2400° F. In short, experiment shows that the nodule treated with dolomite is as strong as the nodule treated with limestone.

In the copending application, applicants had success with magnesite and magnesia. At least to date, applicants have been unable to make either of these work in their taconite agglomerate surface hardening process. This is explainable by the fact that magnesium oxide and iron oxide do not form a eutectic but enter into a solid solution. (Journal of the American Ceramic Society, vol. 30, No. 11, page 27, Figure 58.) This inability of the pure magnesium carbonate to form a glaze on the surface of the taconite nodules at temperatures under 2500° F. confirms applicants' conclusion that the bonds which they are forming are calcium ferrite or calcium-magnesium ferrite bonds and not merely silicates.

While applicants use calcium carbonates and magnesium carbonates because limestone and dolomite are cheap, the invention is not limited to these two substances. The characteristics which the added substance must possess are ability to unite with iron oxide to form a strong bond, and ability to enter into this union at a temperature in the neighborhood of 2400° F.

The final important step in applicants' process is determining how to get the lime on the surface of the taconite agglomerates in commercial production. This is easily done in the case of the nodulizing process because the requisite temperature actually occurs in that process as the nodules move immediately under the flames of the final burner. The step which applicants insert into the present process of nodulizing taconite consists in introducing lime, limestone, or dolomite, generally in a grain size of 200 mesh or smaller into the primary or secondary air supplied for the hard flame burner **22** in a quantity sufficiently small so that with an even dispersion of the flame over the tumbling nodules passing under the hard flame burner **22**, the heated powder composition does not cover, but rather is sparsely dispersed over the nodules so that only a limited fluxing occurs.

The calcium oxides and magnesium oxides do not volatilize even though they are dispersed through the hard flame of the burner **22**. The melting point of either calcium oxide or magnesium oxide is in excess of 2300° C., or in the neighborhood of 4500° F. The volatilization point is far higher. In this respect, the coating agent is to be contrasted with the various chlorides, such as ordinary salt, which are used to vitrify or fuse or glaze ceramic wear. The chlorides volatilize in the flame heat and attack the surface of the ceramic and perform their

function there initially in vapor form. Applicants' problem is to spray thinly powdered material (CaO or CaO—MgO mixtures) which at all nodulizing temperatures can neither be fused nor vaporized. These powdered oxides, however, form with the materials of the nodules eutectics which are slightly below the temperature of the nodules adjacent the hard flame burner.

Impinging powdered lime or dolomite on the tumbling nodules differs from moving the nodules through an atmosphere of this powdered material only by way of degree. In U. S. Letters Patent 2,703,445, dated March 8, 1955, the applicant Veale discloses a process of treating the surface of ordinary refractory brick with these same compounds for the purpose of hardening the surfaces. In this application, the bricks are in a kiln for a long period of time and the flow of air is comparatively slow, much slower than the flow of air arising from the main burner **18** of Fig. 1 of this application. Moreover, the refractories are fixed in size and are not growing.

In the present application, powdered calcium carbonate or calcium-magnesium carbonate can be introduced to the chamber through the primary or secondary air intake of the main burner which is not directed into the nodules. Consequently, they would be blown toward the feed end **26** of the kiln and there they would deposit on the smaller nodules at that end and thereby weaken the nodules. At 2200° F., they would become soft and lose their shape. The composition of the present charge it not to be varied. Applicants' introduction of the high eutectic flux is to increase the hard surface characteristic of each nodule by adding ceramic bonds at the surface only. Referring to Fig. 1, applicants wish to create a zone between the dotted lines **36** and **38** where the hard flame **22** is maintaining the nodules at their highest temperature, in which zone there will be sufficient powdered calcium and magnesium oxide to coat slightly each of the tumbling nodules so that a localized fluxing or a fluxing in situ occurs. This may not establish a completely glazed surface, but rather a large number of glasslike bonds spaced from each other to provide better access to the interior of the nodule. A fully glazed surface is not desirable because it delays the penetration of the blast of a blast furnace. The ideal is the nodule as presently formed plus a partially interrupted glassy surface formed by calcium and/or calcium-magnesium ferrites or any other calcium or magnesium compound which is formed at a temperature below the maximum nodulizing temperature of about 2400° F. to 2500° F.

The grain size of the material added may range from 100 mesh to much finer. This is dependent more upon the type of nozzle used and the velocity of the air. The finer the particle, the smaller the surface bond, and with equal weights of material, the more numerous the bonds. In general, as the examples disclosed below show, applicants utilize a 200 mesh powder.

As for the quantity of surface reinforcing material that is introduced, this will depend firstly, upon how the material is applied to the nodules. This will depend in turn upon the type of burners used in the kiln. If a hard flame burner directed upon the tumbling nodules in a comparatively small area is utilized, the result will be that practically all of the powder (if not applied in excess) will be impinged upon the nodules in such a fashion that all will be utilized in a fluxing action on the nodule surface. Very little will escape in the gases out the feed end of the kiln. On the other hand, if the kiln is utilizing only a soft flame burner, the nodules should be exposed to picking up this powdered reinforcing material for a greater period of time, that is, over a longer distance of travel in the kiln. This means that the air in the upper part of the kiln should be more saturated with this reinforcing powder and the result inevitably will be that more of the powder will be blown out the end of the kiln with the gases and more will have to be introduced in order to properly coat the nodules.

Where the hard flame burner is used to disperse the powder, the quantity may vary from about ⅛ to ¾ of a pound of the reinforcing material to one cubic foot of taconite charge. Inasmuch as the ground taconite weighs 200 pounds per cubic foot, the formula may be stated as ⅛ to ¾ lbs. of reinforcing material to 200 lbs. of taconite fines.

A few examples will clarify the process.

Example I

In a kiln having a main soft flame burner and an auxiliary hard flame burner directed toward the tumbling nodules, with the feed end of the kiln being charged continuously with one cubic foot of taconite fines per unit of time, applicants introduce into the primary or secondary air line of the same burner, one-half pound of powdered limestone having a grain size of 200 mesh or smaller. The powdered limestone will form no part of the combustion step, but preferably it should acquire a sufficiently high temperature in the combustion space so that the $CaCO_3$ converts to CaO plus CO_2 with the result that when CaO strikes the surface of the nodules, the bond between the calcium carbonate and the iron oxide is substantially instantaneously formed because the two combining elements, while well below their own fusion points, are above the eutectic temperature. A good way is to add the powdered limestone to a flowing stream of air which is to become the primary air for the coal combustion. This air can be moved through baffles or other types of obstacles so as to disperse the limestone particles throughout the air. In turn, when this air picks up the coal, it disperses the coal uniformly throughout its volume so that at the point of combustion, there is a proper amount of air adjacent each coal particle, and these limestone particles will, therefore, be dispersed at the points of combustion between the air and the coal. As the nodules flow through the zone **36—38**, see Fig. 1, the nodules in their final size acquire the surface bonds.

Example II

With the same kiln conditions described under Example I, dolomite ground to a mesh of about 300 is introduced to the primary or secondary air intake of the hard flame auxiliary burner **22** in an amount of ⅜ pound per cubic foot of charge. In this case, the burner should be positioned for a minimum distance between the nozzle and the tumbling surface of the nodules. Every effort should be made to impinge all of the products of combustion upon the work, giving the secondary air a minimum chance of blowing away any of the particles. What actually happens is that particles which escape from the direct blast are swept upwardly where they are caught and carried on down the kiln by the lazy flame from the main burner.

Example III

The conditions are identical with the first example excepting that the kiln is equipped only with a main burner. In this case, it is desirable to maintain the mesh size of the reinforcing material comparatively large so that there will be a tendency for the reinforcing material to fall by gravity upon the tumbling nodules. Here, applicants introduce the reinforcing material in a mesh size of approximately 100.

Example IV

Burned iron ore agglomerates at room temperature are passed through a water slurry of powdered limestone, lime or dolomite. They are then moved to an oven where they are heated to a temperature of about 2400° F. The rate of heating is not important. The process can be performed by moving the agglomerates on a conveyor through a kiln.

The process is applicable to the briquetting method in the way discussed in the copending application Serial No.

205,222, but magnesite and magnesia are not useful at the temperature disclosed in this application.

The process can be used for pelletizing by adding a stage of heating the pellets to a temperature of about 2400° F., and then reinforcing the surface of the pellets during a tumbling operation by the same process described for the nodulizing in the zone **36—38** of Fig. 1. In the pelletizing process, the taconite is initially mixed with a charge of a binder such as bentonite and clay and pulverized coal. It is then moved into a balling drum where ingredients are agglomerated into balls the size of a walnut. From this balling drum, the pellets move on a conveyor through a furnace which burns the coal to form what are really small bricks. The temperature is not carried to a point above 2000° F. and strength is obtained primarily from the aluminum silicate bonds which are obtained by the burning of the clay. However, there is present on the surface of the pellets as they come from the burning furnace sufficient Fe_2O_3 to form with limestone or dolomite the type of ferrite bonds disclosed by applicants herein and all that is necessary is raising the temperature to about 2400° F. at the end of the kiln and providing means to suspend the reinforcing particles in the air. Pelletizing has been performed in the same equipment as that used for nodulizing. A long rotary kiln is employed and the balling of a binder such as clay or bentonite with the taconite occurs at the feed end of this kiln. The balls quickly build up in size and thereafter move through the kiln at a substantailly constant size. During this movement, they are heated to a temperature of about 2000° F., the clay forming a bond well below this heat. In order to adapt applicants' process to this kiln method of forming pellets, it will be necessary to raise the temperature of the pellets still higher, that is, to a point some place near 2400° F.

The process described in this application is applicable to agglomerating hematite, which may become important for ore such as that found in Venezuela. The Venezuelan ores are highly pulverized and pelletizing is anticipated.

Applicants have attempted to verify the existence of the calcium oxide, magnesium oxide, iron oxide eutectic, but have been unable to find the phase diagram disclosing this. Professor Ralph E. Grimm, Research Professor of the Department of Geology of the University of Illinois, a consultant of the assignee of applicants, states that to his knowledge no one has determined this, and that probably the better way of explaining the action of the dolomite is to state that in some instances the calcium ferrite bonds are replaced by magnesium ferrite bonds. Therefore, the explanation of "calcium-magnesium oxide" found in the above and in the claims that follow, should be interpreted in the light of Professor Grimm's suggestion. The exact structure of the calcium-magnesium ferrite is not clear.

Where the word "nodules" is used in the claims, it includes pellets or any agglomerates that are being grown in a rotating kiln. Where the word "agglomerates" is used, it includes all usable sizes of iron ore masses or lumps, including bricks.

Having thus described applicants' invention, what they claim is:

1. The method of strengthening iron ore agglomerates having substantial quantities of iron oxide in their surfaces which comprises contacting under oxidizing conditions the surface of said agglomerates with smaller particles composed essentially of an alkaline earth oxide selected from the group consisting of calcium oxide and calcium-magnesium oxide with the surfaces of the agglomerates at a temperature of at least the fusion temperature of the eutectic of iron oxide and said alkaline earth oxide under condtions permitting formation of a eutectic of the iron oxide and the alkaline earth oxide.

2. The method of strengthening iron ore agglomerates having substantial quantities of iron oxide in their surfaces which comprises the steps of heating the agglomerates to a temperature above 2300° F., of suspending particles composed essentially of calcium oxide of a size such as pass through a 100 mesh screen in the fuel used for heating, and of contacting the calcium oxide particles therein with the surfaces of the agglomerates under oxidizing conditions permitting the formation of a eutectic of the iron oxide and the calcium oxide.

3. The method of strengthening iron ore agglomerates having substantial quantities of iron oxide in their surfaces which comprises the steps of heating the agglomerates to a temperature above 2300° F., of suspending particles composed essentially of a mixture of calcium oxide and calcium-magnesium oxide of a size such as pass through a 100 mesh screen in a flammable gas, and of contacting the mixture of calcium oxide and calcium-magnesium oxide particles therein with the surfaces of the agglomerates under oxidizing conditions permitting the formation of a eutectic of the iron oxide and the mixture of calcium oxide and calcium-magnesium oxide.

4. The method of strengthening iron ore agglomerates having substantial quantities of iron oxide in their surfaces which comprises the steps of heating the agglomerates to a temperature above 2300° F., and of impinging on the surface of the agglomerates under oxidizing conditions particles composed essentially of a material selected from the group consisting of calcium oxide and calcium-magnesium oxide under conditions permitting formation of a eutectic of the iron oxide and the material selected from the group consisting of calcium oxide and calcium-magnesium oxide.

5. The method of strengthening iron ore agglomerates having substantial quantities of iron oxide in their surfaces which comprises the steps of heating the surface of the agglomerates to a temperature above approximately 2300° F., and of impinging particles composed essentially of calcium oxide on the agglomerates under conditions permitting formation of a eutectic of the iron oxide and the calcium oxide.

6. The method of strengthening iron ore agglomerates whose surfaces contain in excess of 50 percent iron oxide which comprises the steps of heating the agglomerates to a temperature above 2300° F., and of forming on the surfaces of the agglomerates under oxidizing conditions a glaze composed essentially of the eutectic reaction product of a material selected from the group consisting of calcium oxide and calcium-magnesium oxide with the iron oxide of the agglomerates, said glaze being formed by contacting particles composed essentially of said material with the surfaces of the heated agglomerates.

7. The method of surface strengthening taconite nodules having substantial quantities of iron oxide in their surfaces which comprises the steps of raising the temperature of the surfaces of the nodules to a temperature of 2300° F., and of contacting under oxidizing conditions small particles composed essentially of a material selected from the group consisting of calcium oxide and calcium-magnesium oxide with the surfaces of the nodules to react with the iron oxide to form ferrite bonds.

8. In the method of modulizing taconite agglomerates containing iron oxides in their surfaces wherein nodules are grown in a kiln by tumbling and heating under oxidizing conditions to a temperature in excess of 2300° F., the step of passing the nodules at such temperatures through an atmosphere having dispersed therein particles composed essentially of and selected from the group consisting of calcium oxide and calcium-magnesium oxide so that the particles deposit on the surfaces of the nodules to form ferrite bonds with the iron oxide in the taconite.

9. In the method of nodulizing taconite agglomerates containing iron oxides in their surfaces wherein nodules are grown in a kiln by tumbling and heating under oxidizing conditions to a temperature in excess of 2300° F., the steps of heating solid particles composed essen-

tially of calcium carbonate to a temperature approaching that of the eutectic temperature of calcium oxide with Fe_2O_3, and of suspending these heated particles in the path of the nodules at a point where the surface temperature of the nodules is in excess of said eutectic, so that the particles deposit on the surfaces of the nodules and form with the iron oxide a bond.

10. In the method of strengthening taconite nodules containing iron oxides in their surfaces formed under oxidizing conditions in a rotary kiln at a maximum temperature which is above the fusion temperature of the eutectics of iron oxide and a material selected from the group consisting of calcium oxide and calcium-magnesium oxide, the step of suspending in the air of the kiln in the zone where the nodules attain their highest temperature solid particles composed essentially of at least one of said materials as the nodules move through this zone of suspended particles, the particles contacting the surfaces of the nodules to form with the iron oxide in the taconite ferrite surface bonds.

11. The method of surface strengthening iron ore agglomerates containing substantial quantities of iron oxides in their surfaces which are being nodulized under oxidizing conditions in a rotary kiln having a zone where the agglomerates are heated above 2300° F., which comprises the additional steps of suspending particles composed essentially of a material selected from the group consisting of calcium oxide and calcium-magnesium oxide in a combustible mixture for the kiln burner, and of burning the mixture in contact with the nodules in that zone in the kiln under conditions permitting formation on the surfaces of the agglomerates of a eutectic of the iron oxide and the material selected from the group consisting essentially of calcium oxide and calcium-magnesium oxide.

12. In the nodulizing of iron ore fines in a rotary kiln employing a main lazy flame burner and an auxiliary hard flame burner directed toward the advancing nodules at a point where they have grown to their full size and

are at a temperature above 2300° F. and contain substantial quantities of iron oxide in their surfaces, the step of introducing into the combustion space of the auxiliary burner particles composed essentially of a material selected from the group of calcium oxide and calcium-magnesium oxide and having a size of less than 100 mesh, under conditions permitting formation of a eutectic of the iron oxide and the material selected from the group consisting of calcium oxide and calcium-magnesium oxide.

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