This invention relates to grinding balls and their production, and more particularly to balls used in rotary grinding mills or the like in which ore, coal, or other similar material is reduced to a relatively finely divided state.

Previously, grinding balls have been of three general compositions—cast iron, cast steel, and forged steel. Cast iron grinding balls have central voids or pores which render the center relatively weak in resistance to shock, although the exposed surface is highly resistant to abrasion and wear. Cast steel grinding balls are relatively expensive to produce, and in particular, they become too expensive for ordinary operations if insufficient alloying elements are included to increase sufficiently the resistance to shock and wear. Forged steel grinding balls, when made of a proper alloy steel, are resistant to both wear and shock, but are expensive.

Among the objects of this invention are to provide a grinding ball, particularly useful in standard ball mills, which will be economical to produce and which will not only be uniformly highly resistant to wear, but also resistant to shock; to provide such a grinding ball which may be made of cast iron, without expensive alloying agents; and to provide such grinding balls which require a minimum of expensive equipment, materials, or operations for manufacture.

The method of this invention, for producing a grinding ball which is highly resistant to wear and shock preferably consists of casting iron substantially in the form of a sphere, and forging the sphere to reduce the size thereof. The pre-compressed sphere may be suitably heat treated, as by heating and quenching from a suitable hardening temperature, and then tempered at a suitable lower temperature to increase the toughness.

The cast iron may be any suitable cupola or equivalent iron possessing a pearlitic matrix of a chemical analysis approximating 3.00–3.10% C, of which not less than 0.22% is in the combined form: Si 1.20–1.30%, Mn 0.90–1.00%. This analysis is necessary to insure obtaining the desired Brinell of 450 and uniform hardness. The remainder of the carbon will be in the form of free graphite dispersed throughout the matrix, said free graphite being approximately 7% by volume of the matrix and it has been found that the graphite flakes on the surface, when the balls are in service in a grinding mill, disintegrate or eradicate themselves on impact, leaving molecular voids in the surface which hold and carry the grinding fluid around with the ball as it is revolved and rotated. This condition has a beneficial effect in avoiding metal-to-metal contact to a large degree, with consequent lessening of shock and reduction in wear.

The forging step, applied to a cast iron sphere in accordance with this invention, has been found to increase the density of the sphere by reducing, or eliminating entirely, the voids normally found in the interior of a cast iron grinding ball. The volume of the sphere may be decreased by 20% or more, thus producing a heavier, closer grained, and more uniformly solid ball. The uniformity of solidity, as well as the forging and effect of void elimination, apparently increases considerably the resistance of the ball to shock, thereby eliminating one of the major difficulties encountered in the use of other types of cast iron grinding balls. At the same time, the high resistance to wear and abrasion of cast iron is retained in the ball, and a more useful ball having a much longer life is thereby produced. Also, cast iron is a relatively cheap material, compared with alloy cast iron and special steel, and a grinding ball of this invention is relatively cheap.

The forging step of this invention is preferably applied to an article already spherical or spheroidal in shape, and may be accomplished by a single set of dies in a suitable hammer. Preferably, the cast iron sphere is hot forged after heating to a temperature of from 1500° to 1700° F., and the sphere may be quenched in water or other suitable cooling media after forging to save the expense of reheating for hardening. After hardening, the forged sphere may be tempered by quenching in oil or other suitable media from a suitable tempering temperature, or immersing in a suitable tempering media at a lower temperature for a period of time. Preferably, the hardening and tempering operations are so carried out that the balls have a resulting hardness of 450 to 470 Brinell, although any desired hardness between 200 and 500 Brinell can be produced.

The cast iron may be melted in a convenient cupola, from a charge of cast iron and steel scrap, with small amounts of manganese, ferro-silicon, or other constituents to control the chemical analysis. The cast iron is preferably poured into sand molds to form balls or spheres of suitable diameter. After cooling in the molds, the cast iron spheres may be removed and heated to the forging temperature, and then placed in a forging hammer, a pressure forging machine, or other suitable apparatus. The dies of the forging apparatus may be one fourth inch smaller in diameter, for instance, than the spheres as cast, and
the spheres are compressed to the size of the forging dies. After the forging operation, the temperature of the spheres may be sufficiently high to permit quenching for hardening purposes, or the spheres may be reheated to a suitable hardening temperature.

In using the term "cast iron" in the specification, it is intended to designate high strength cast iron made by the cupola process, or equivalent compositions otherwise produced.

As an example of grinding balls made in accordance with this invention, the following is cited: 3\% inch diameter spheres were cast from a cast iron having approximately 3.00\% carbon, of which 0.82\% was combined; 1.25\% was silicon; 0.12\% phosphorus; and 0.90\% manganese.

The foregoing cast iron is, of course, pearlitic due to the percentage of combined carbon. After cooling, such cast iron balls were heated to a forging temperature of 1650\°F to 1700\°F, and then placed in forging dies adapted to reduce the diameter of the balls to about 3 inches, which is a reduction in volume of approximately 21.5\%.

The density of the cast iron ball was, of course, correspondingly increased.

Thereafter, depending upon the facilities available, the cast iron balls may be quenched directly after the hot forging operation from a temperature of approximately 1580\°F, as was done in this instance, or they may be reheated to the quenching temperature prior to quenching in water or other suitable media adapted to produce a Brinell hardness of about 600. After hardening, the balls were tempered in oil at about 375\°F for approximately 30 minutes, to increase the toughness thereof, the Brinell hardness thereby being reduced to 450-475. The toughness produced by the tempering operation prevents shatter, while the forging operation eliminates shrinkage voids in the center of the ball, and in effect, densifies the body.

From the foregoing, it will be evident that the method of this invention produces grinding balls which have a very long life due to the hardness and resistance to wear, combined with toughness and resistance to shock. At the same time, such grinding balls can be formed of relatively cheap material, and can be produced for a total cost which is only slightly greater than that of ordinary cast iron balls, and considerably less than that of special alloy cast iron balls, or forged plain or alloy steel balls. Further, the process is performed in a way that removes little if any material of the original casting, and the final product although substantially reduced in size has the equivalent weight of the starting material.

It will be understood that the analysis of the cast iron grinding balls produced in accordance with this invention may vary rather widely and that the forging, hardening, and tempering temperatures will vary with the analysis, in accordance with the best forging and heat treating practices. It will also be understood that the forging and heat treating steps may be varied to take advantage of whatever facilities are available and that the reduction in volume may be greater or less than the example described. It will further be understood that other variations of this invention may be made, all without departing from the spirit and scope thereof.

What is claimed is:

1. A method of producing a grinding ball which comprises pouring cupola melted iron into a mold, to produce a cast iron sphere having a pearlitic structure; permitting said sphere to cool in said mold; removing said sphere from said mold; heating said sphere to a forging temperature; hot forging said sphere to reduce the volume and increase the density while maintaining the spherical shape thereof; heating said sphere to an elevated temperature and quenching to harden the same; and tempering said sphere at a predetermined lower temperature to produce a predetermined toughness.

2. A method of producing a grinding ball which comprises forming, by casting, a sphere of pearlitic cast iron having not less than 0.82 per cent combined carbon; heating said cast iron sphere to a forging temperature above the critical range; hot forging said sphere to reduce the volume thereof by about 20 per cent, while maintaining the spherical shape thereof; hardening said sphere by quenching from a temperature above the critical range; and tempering said sphere at a temperature below the critical range.

3. A method of producing a grinding ball as defined in claim 2, wherein said cast iron consists of approximately 3.00 to 3.10 per cent total carbon, 1.20 to 1.30 per cent silicon, 0.90 to 1.00 per cent manganese, the balance substantially iron, and said hardening and tempering operations produce a Brinell hardness of about 450 to 475, substantially uniform throughout the cross section of said sphere.

4. A method of producing a grinding ball as defined in claim 2, in which said cast iron includes sufficient carbon to form free graphite, and said forging, hardening and tempering operations leave such graphite dispersed throughout the matrix, whereby such graphite flakes on the surface of said grinding ball when in service, thereby tending to leave molecular voids in the surface which hold and carry fluid around with the ball.

MANLEY R. NELSON.

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