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METHOD AND APPARATUS FOR FORMING SOLIDIFIED
PARTICLES FROM MOLTEN MATERIAL
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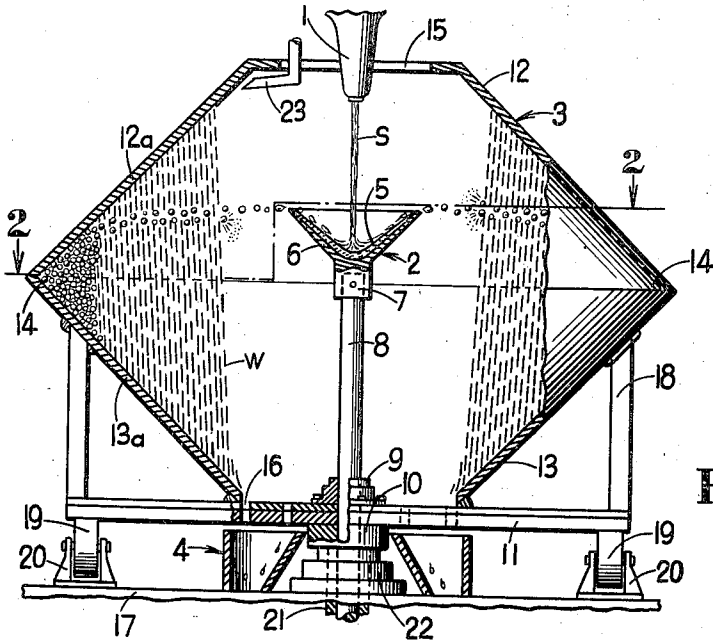


Fig. 1

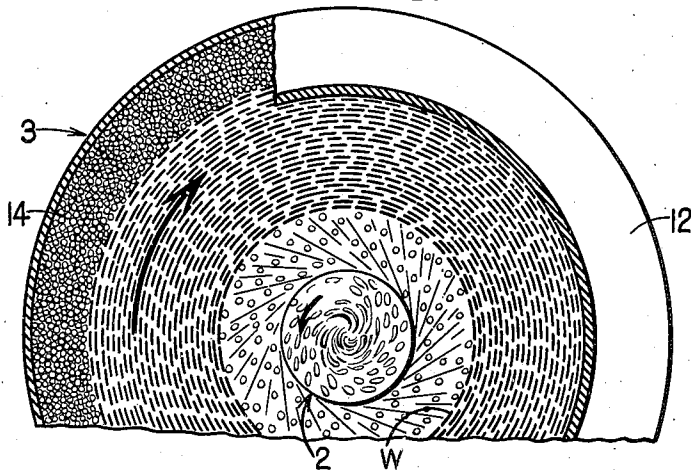


Fig. 2

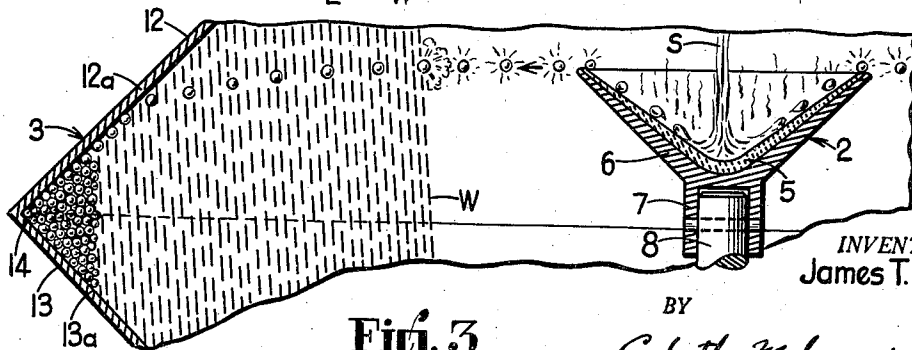


Fig. 3

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METHOD AND APPARATUS FOR FORMING
SOLIDIFIED PARTICLES FROM MOLTEN
MATERIALJames T. Gow, Columbus, Ohio, assignor, by
mesne assignments, to Steel Shot Producers,
Inc., Butler, Pa., a corporation of Delaware

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My invention relates to method and apparatus for forming solidified particles from molten material. It has to do, more particularly, with a method and an apparatus that are especially useful for disintegrating molten metal into comparatively small droplets which are solidified into solid particles or pellets that are relatively round, non-oxidized, and of desirable hardness. The method and apparatus described herein are effective for forming shot from molten metal, especially steel shot, although they are not limited to this application.

The production of metal shot is an old and well-known art. A large number of different processes and apparatuses have been designed and used for shotting various metals. However, certain industrial applications for metal shot have been in the process of development in recent years which require shot of metals other than those commercially available or shot having improved physical, mechanical or chemical properties over the shot that can be produced by any of the known commercial processes or devices. For example, the problem of shotting oxidizable metals has not been solved successfully in the art, prior to my invention, and there is still no apparatus known to the art which is capable of successfully accomplishing this operation.

The prior art has used mainly three basic methods of disintegrating molten metal in the form of a stream into droplets which are solidified into small particles or pellets. One method consists in impacting a vertically falling thin pencil of molten metal with a jet of high pressure steam or water. A second method consists in dropping a thin stream of metal onto the surface of a rapidly rotating drum or paddle wheel arrangement which throws or bats the globules through the air. The third method is a centrifugal disintegrating process and consists in throwing droplets of molten metal from the periphery of a revolving cup or receptacle into which a stream of the molten metal discharges. With all three processes, the particles are generally passed through air for some distance to become solidified or partially solidified before they lose momentum sufficiently to drop into a tank of water or other cooling liquid having its top surface somewhat below the level at which the molten metal stream is disintegrated into globules. Disintegration of the molten metal stream by a jet of high pressure steam or water, according to the first method, is unsuitable because of a lack of control of particle size and shape. The same is true of the second or mechanical paddle wheel

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method. With all three methods, however, one of the most objectionable features is that they cannot be used for shotting readily oxidizable metals because the droplets must travel such a long distance through the air prior to dropping into the liquid cooling medium and during this long travel the droplets become ignited and oxidized.

Numerous machines have been designed and used in the past in attempts to make the centrifugal disintegrating process a commercially feasible one for producing shot particles, but none to my knowledge has found commercial acceptance from the standpoint of economy or being capable of providing desired non-oxidized and relatively sphere-shaped particles in substantial amounts. One of the prior art machines for shotting cast iron by the centrifugal disintegrating process which, as described, comprises a centrifugal throwing cup having means associated therewith for discharging metal into said cup. Below the level of the cup is a large tank, approximately 30 feet in diameter, which holds a body of water into which falls the shot thrown from the cup. Before falling into the water, however, the shot travels through the air for a long distance of about 5 to 15 feet from the throwing cup. Due to this long travel through the air, the finely divided iron particles oxidize before dropping into the water. The apparatus necessarily is so large that it takes up an excessive amount of floor space and, furthermore, is expensive to operate. Also, because of the great size of the apparatus, it is difficult to convey the molten metal, and still maintain it in proper condition for shotting, from the melting furnace to the centrifugal throwing cup which must be located at the center of the large-diameter water tank. Other machines have been produced for making steel shot or other oxidizable metal shot, but none of them has proved practical from a commercial standpoint and have, therefore, been abandoned.

At the present time there has arisen a greatly increased need for metal shot, especially steel shot, due primarily to the fact that metal peening, a relatively recent innovation, has assumed considerable importance in the metal treatment art. In fact, the demand for a relatively tough, hardened steel shot of small particle size and relatively spherical shape, suitable for metal peening, has been so great that the same processes employed in producing ball bearings have been tried in the production of the steel shot of this type which is not at present being otherwise commercially produced. Obviously, this type of proc-

ess, embodying difficult forging and grinding operations, is prohibitive as to cost even in producing the larger sizes of shot, such as $\frac{1}{8}$ to $\frac{1}{2}$ inch diameter shot. Moreover, the small shot required for most peening operations is from 0.015 to 0.050 inch diameter and this small size cannot possibly be produced by this ball-bearing type of process.

One of the objects of my invention is to provide method and apparatus for forming solidified particles from molten material in an efficient and economical manner, the particles produced being of desired shape and size and having desired hardness and other properties.

Another object of my invention is to provide method and apparatus for disintegrating various molten materials, and especially a number of different metals, into small droplets which are solidified into particles or pellets, with such economy and efficiency in obtaining particles of desired characteristics and properties as to be commercially feasible.

Another object of my invention is to provide method and apparatus for forming solidified particles from molten material capable of use in forming particles from readily oxidizable materials in such a manner as to preclude oxidation of the particles during the formation thereof.

Another object of my invention is to provide method and apparatus for forming solidified particles from molten material capable of being regulated and controlled so that there can be produced economically particles of pre-selected size, of desired hardness and of uniform spherical shape.

Another object of my invention is to provide a method for forming solidified particles from molten material which is of such a nature that it may be performed in apparatus which is of small size, compared with prior art apparatus, and which, therefore, occupies a small amount of floor space and can be supplied readily with the molten material in proper condition for the disintegrating operation.

Still another object of my invention is to provide apparatus which will be effective in performing the method referred to above, which is not only of small size, but is of simple and inexpensive structure, and which is easy and economical to operate and maintain.

Other objects will be apparent from the following description.

According to my invention, the molten material is discharged, from a pouring funnel or the like, in the form of a stream into a dish-shaped receptacle which is rotating about its own vertically disposed axis at a high rate of speed and which will throw the metal from its periphery in the form of small globules. The rate of delivery of the molten material into the dish-shaped receptacle and the speed of rotation of the receptacle, are selected to produce solid particles or pellets of desired size which result from solidification of the small globules thrown from the receptacle. By regulating the rate of delivery of the molten material to the receptacle relative to the speed of rotation of the receptacle, the size of the particles produced may be varied. The temperature of the molten material is sufficiently high that it will readily flow through the pouring funnel and will be disintegrated into small globules by the spinning dish. On the other hand, the temperature of the material is not so high as to render it too fluid so that it will be thrown off the receptacle too quickly and will

not be in the form of globules and will not solidify sufficiently quickly after coming into contact with the cooling medium, as will later be apparent.

The spinning receptacle is dish-shaped, as indicated above, and the stream of molten material impinges on the center of the flat bottom thereof. The angularity of the side wall of the receptacle is such that the centrifugal force tending to throw the molten material off the dish is offset to a small degree by the inclined side wall up which the molten material must climb before it is discharged from the dish. This retardation of discharge from the dish results in the molten material rolling around in the dish and up the side wall so that by the time it is discharged, it will be in the form of small separate globules which are of substantially spherical form. Thus, the speed of rotation of the dish also depends somewhat upon the angularity of the side wall of the dish. It is preferred that the speed of rotation of the dish and the temperature and rate of feed of the molten material to the dish be such that a slight head of molten material will be maintained in the bottom of the dish.

Surrounding the spinning dish, I provide a revolving container which contains a suitable cooling or quenching liquid, such as water. This container is so shaped and of such size that when it is revolved at a proper speed, the cooling liquid contained therein will be formed into a revolving annular vertical wall of liquid into which the globules of molten material, thrown off substantially horizontally by the spinning dish, after traveling unsupported through the ambient atmosphere a short distance, will be thrown. In passing through the atmosphere unsupported, the molten globules are formed into more nearly perfect spheres. The path of the globules from the spinning dish is substantially normal to the wall of the liquid in the vertical plane and substantially tangential to the rim of the throwing dish in the horizontal plane. The departure from normal, relative to the curved inner surface of the liquid, in the horizontal plane is relatively slight and is not sufficient to cause the globules to glance off the liquid surface, as is known to happen in some processes which are now in use. It is only necessary in my process to have the normality of the path of the globules to the wall of the liquid such that the globules will penetrate the liquid rather than glance off, and that condition is readily maintained with my apparatus and is referred to in this specification and in the claims as "substantially normal." Furthermore, this arrangement and the fact that the wall of liquid is revolving, causes further spinning of the globules as they strike the surface of the wall of liquid and thereby offsets the tendency for the globules of molten material to flatten upon striking the cooling liquid. Consequently, the spherical shape of the globules is maintained.

The distance between the periphery of the spinning dish and the wall of quenching liquid is critical. This distance must be such that the globules will enter the liquid before they have had a chance to oxidize. The wall of quenching liquid must be of sufficient extent in the direction of travel of the globules which enter thereinto that the globules will be cooled by the liquid to the solidification point before they strike the wall of the revolving liquid container. The peripheral wall of the container is so shaped that this is accomplished with a minimum amount of cooling liquid, thereby resulting in a decrease in the required size of the apparatus and making

the apparatus more economical to operate. The peripheral wall of the container is so shaped that a pocket is provided for collecting the pellets or solidified particles and that the pellets will feed into said pocket as they are formed by solidification of the globules of molten material which are thrown into the quenching liquid. Thus, the globules will enter the quenching liquid before they can be harmed by oxidation and upon entering the wall of liquid, they will be fully quench-hardened.

In the accompanying drawing I have illustrated one form of apparatus which I have provided for use in performing my method. In this drawing:

Figure 1 is a view mainly in vertical section, but partly in elevation, illustrating apparatus in use in performing my method.

Figure 2 is a horizontal sectional view taken along line 2—2 of Figure 1.

Figure 3 is an enlarged view in vertical section showing the spinning cup and associated liquid container in operation in forming the pellets.

With reference to the drawings, I have illustrated one form of apparatus which can be used in performing my method. This apparatus includes only the basic units which are necessary in the performance of my method. However, it is to be understood that the design and structure of this apparatus may vary widely as long as the basic units and basic principles of operation are retained.

The apparatus shown comprises in general a funnel unit 1 for supplying the molten material, a spinning dish 2 into which the stream of molten material is discharged and which disintegrates it into the form of globules, a revolving container 3 concentric with the spinning dish and adapted to contain the quenching liquid in the form of an annular vertically disposed revolving wall of liquid into which the molten globules are thrown after flying from the spinning dish, and a discharge chute 4 of annular form disposed below the container 3 and adapted to receive the solidified pellets when they are discharged from the container.

The funnel 1 may be of any suitable type for receiving molten material and feeding it downwardly in the form of a thin stream. It preferably is provided with means (not shown) for varying the size of the stream of molten material fed therefrom and the velocity of the stream issuing therefrom.

The spinning dish 2 is preferably provided with a liner 5 of refractory material. The dish is provided with an outwardly and upwardly flared side wall 6. As will later appear, the angularity of this side wall is important.

The dish 2 is provided with a downwardly projecting centrally disposed boss 7 which has a socket formed therein for receiving the upper end of a shaft 8 which is vertically disposed. The shaft 8 is keyed to the boss 7 so that when the shaft is driven, the dish 2 will be rotated about its own vertical axis. The dish is removable to permit replacement with different size dishes. The lower end of the shaft 8 passes rotatably downwardly through bearing structures 9 and 10 which are disposed above and below, respectively, a supporting base plate 11. The lower end of the shaft 8 may be driven by any suitable variable speed drive.

The container 3 may be formed of metal and may be of the shape shown in Figure 1. It consists

of an upper frusto-conical section 12 and a lower inverted frusto-conical section 13. The two sections 12 and 13 have their larger diameter edges in contact and may be welded or otherwise secured together or the entire container may be formed of integral sections. Thus, the meeting edges of the sections 12 and 13 form a pellet collecting pocket 14 which is of angular cross-section with the vertex of the angle directed outwardly. The angularity of the side wall 12a of the upper section 12 is important, as will later appear, and should be at such an angle to the horizontal that the pellets will move rapidly into pocket 14. Good results have been obtained when the angle has been less than 45° to the horizontal. This will insure that the pellets upon striking the inner surface of the wall 12a will be fed downwardly and outwardly by centrifugal force into the collecting pocket 14. The angularity of the side wall 13a of the lower section 13 is not so important except that it should be directed inwardly at a sufficiently sharp angle that when the speed of rotation of the container 3 is decreased sufficiently, the pellets which collected in the pocket 14 will slide downwardly along the inner surface of the wall 13a.

It will be noted from Figure 1 that the upper end of the container 3 is provided with a centrally disposed opening 15 through which the funnel 1 may be inserted into the container 3. It will also be noted that the upper edge of the spinning dish 2 is at a level which is intermediate the height of the angularly disposed side wall 12a. The lower edge of the section 13 is suitably secured, as by welding, to the base plate 11 which is of disk-like form. This plate 11, consequently, forms the bottom of the container 3. This bottom is provided with a series of discharge apertures or slots 16. These apertures 16 discharge into the annular discharge chute 4 which may be supported by a suitable frame structure or table 17 which supports the entire machine. At the periphery of the base plate 11, upstanding supports 18 are carried thereby and have their upper ends secured to the side wall 13a of the section 13, in order to provide a rigid support for the container 3. The base plate 11 rests on rubber tired supporting rollers 19 which are supported adjacent the periphery thereof by means of U-shaped brackets 20 that are secured to the upper surface of the frame 17. For rotating the plate 11 and, consequently, the container 3 a sleeve 21 is provided which extends up through a bearing 22, carried by frame 17, and which is attached to the bearing 10 that is secured to plate 11. Thus, when the sleeve 21 is driven, the container 3 will be rotated. The shaft 8 extends downwardly completely through the sleeve 21 and may be suitably driven as previously indicated. The sleeve 21 will be suitably driven, independently of the drive to shaft 8, by a variable speed drive. Thus, it will be apparent that the spinning dish 2 may be rotated at a selected rate of speed and the container 3 may be rotated independently at a selected rate of speed.

Suitable means is provided for supplying the cooling liquid to the interior of the container 3. For example, a supply pipe 23 may extend downwardly through the opening 15 into the upper end of the container. This pipe is directed outwardly towards the side wall 12a.

Generally described, the apparatus operates as follows: The container 3 and the spinning dish 2 are driven at suitable speeds. Liquid is sup-

plied to the interior of the container by the pipe 23. The container is rotated at a sufficiently high rate of speed so that the liquid supplied thereto will form a vertical annular wall, due to centrifugal force, with the inner surface W of the wall of water substantially vertically disposed. The distance of this inner surface W from the peripheral edge of the dish 2 will depend upon the amount of liquid in the container. However, this surface W, obviously, can never be closer to the axis of the dish than the openings 16 which would permit the liquid to leak from the container. The molten material will be supplied into the dish 2 by the funnel 1 from which it issues in the form of a small stream S. When the molten stream strikes the bottom of the dish which is spinning at a high rate of speed, it will be caused by centrifugal force to travel up the inclined wall of the dish and will be thrown outwardly from the upper edge of the dish in a path substantially tangential thereto. By the time the molten material leaves the dish, it will be in the form of globules of molten material which will travel in a nearly horizontal path through the air until they enter the revolving wall of liquid. This revolving wall of liquid will have its inner surface W substantially vertical and, therefore, substantially normal to the horizontal path of travel of the flying globules. The globules will be solidified during their passage through the liquid and before they contact the surface of the side wall 12a of the container. This wall 12a will, due to centrifugal force, direct the solidified particles downwardly into the collecting pocket 14. As previously indicated, the angularity of the wall 12a should be such that the solidified pellets will move downwardly along the inner surface of the wall into the pocket 14, and angles of less than 45° have been found effective. I have found that, if a vertical container wall was used, the pellets piled up in a horizontal ring around the container, and as the process was continued, this mass of pellets extended toward the rotating dish 2 to such an extent that there was insufficient travel in the remaining cooling liquid to solidify the pellets, and they tended to weld into a mass. I have overcome this difficulty by my design of the liquid container in section 12 and prefer to use an angle less than 45° to the horizontal to move the solidified pellets rapidly and effectively out of the position of the incoming pellets and into pocket 14. When it is desired to discharge the solidified pellets from the pocket 14, it is merely necessary to decrease the speed of rotation of the container 3 sufficiently so that gravity will offset the centrifugal force and the pellets will slide inwardly down the wall 13a to the discharge apertures 16. The liquid and the pellets will discharge through the aperture 16 into the chute 4 which may direct them into suitable apparatus where the pellets will be strained from the liquid.

In the practice of my method, for example in the shotting of molten metal, the metal is melted and poured into the funnel 1 from which it issues in the form of the thin stream S. The speed of rotation of the spinning dish 2 into which the stream of molten metal drops is regulated according to the size of shot particle desired and is proportional to the rate of delivery to it of the molten metal from the funnel 1 and to the fluidity of that metal. The fluidity of the molten metal is related to its chemical composition and temperature. The temperature range for satisfactory shotting of the molten metal is related

to the melting point of the metal. I have found it advantageous to have the temperature of the molten metal entering the funnel 1 about 200° F. to 250° F. above the liquidus temperature of the metal or composition being shot. Such an amount of super-heat was found to be about the minimum to allow free flow from the discharge orifice of the funnel, was all that was needed for the centrifugal disintegration, and allowed for the withdrawal of a minimum of heat for solidification of the globules. The maximum usable temperature is determined by the horizontal thickness or extent of the revolving wall of liquid, which in the case of forming metal shot will be water, into which the shot particles are thrown. Sufficient heat must be removed from the globules in their travel through the water wall to cause their solidification into shot particles before they contact the inclined side wall 12a of the container 3. The greater the extent of the water wall, in the direction of travel of the particles thrown thereto, the higher can be the amount of super-heat in the metal. It is evident that, for numerous reasons, it would be uneconomical to super-heat above the melting point of a metal to an extent greater than that required to successfully disintegrate the molten metal into globules. Following are examples of two specific metals illustrating operable and inoperable shotting temperatures:

Example 1

Material:

A 0.45% carbon steel having a melting point (liquidus temperature) = 2730° F.

Satisfactory shotting has been obtained with the molten steel being delivered to the receiving receptacle, which in turn discharges a stream of metal from an orifice onto the shotting dish, at a temperature of 2925° F. plus or minus 50° F.

With the metal temperature at 2840° F., metal froze in the orifice from the receiving receptacle from which it was intended to be discharged at a controlled rate onto the shotting dish.

Using metal temperatures above 3050° F., the majority of metal-shot particles from the shotting dish passed through the water wall and were not solidified when they first contacted the surface of the water container. This resulted in a fusion together of the shot particles into a mat-like mass on the container wall.

Example 2

Material:

A high carbon and silicon content cast-iron composition having a melting point = 2260° F.

Satisfactory shotting was obtained with a metal delivery temperature of 2490° F.

A shotting temperature of 2640° F. proved too high. The shot were fused together into a mat on the wall of the container.

As previously indicated, the angularity of the side wall of the spinning dish 2 is such that the centrifugal force tending to disintegrate the molten material and throw it from the dish is offset to a certain degree by such inclined wall up which the molten metal must climb before being thrown tangentially from the dish. This retardation of discharge from the dish results in a more uniform distribution of the globules thrown from the periphery of the dish and also aids in forming the small separate globules and imparting to them substantially spherical form.

It is preferred to maintain a slight head of molten metal in the bottom of the dish.

With regard to the speed of rotation of the dish 2, the table below illustrates the effect of spinning rate on shot size. This table is the screen analysis of a 0.40% carbon steel product produced with three different spinning dish speeds of 810, 1000 and 1220 R. P. M., which provided peripheral velocities of 22.5, 27.7 and 33.8 feet per second, respectively. The metal-pouring temperature was constant at about 2950° F. and the average rate of metal delivery to the spinning dish was 2.15 lbs. per second. To illustrate the way in which the rotational speed of dish 2 modifies the size of the particles produced, at the bottom of the table are given the percentages of particles within the range of through 12, on 35 (.055-inch to .0164-inch diameter) for the three spinning speeds, and it is shown that, as the speed is increased from 810 to 1220 R. P. M., this percentage increases from about 50 to nearly 90 per cent. This is a range of size which is much in demand by industry for shot peening, but these data are introduced principally to show the flexibility of my method and apparatus and in what way the size distribution of the product can be controlled, which feature has been almost totally lacking in prior methods.

Screen Mesh		Lot 2		Lot 4		Lot 3	
Through	On	Wt. Per Cent	Cum. Wt. Per Cent	Wt. Per Cent	Cum. Wt. Per Cent	Wt. Per Cent	Cum. Wt. Per Cent
-----	7	1.43	1.43	.11	.11	.92	.92
7	8	2.70	4.13	.55	.66	.56	1.48
8	9	7.32	11.45	1.62	2.28	.85	2.33
9	10	16.05	27.50	5.76	8.04	1.51	3.84
10	12	20.79	48.29	13.41	21.45	3.53	7.37
12	14	19.07	67.36	21.10	42.55	13.65	21.02
14	16	17.97	85.33	16.80	59.35	18.32	39.43
16	20	5.07	90.40	13.21	72.56	17.28	56.62
20	24	4.93	95.33	7.93	80.49	11.86	68.47
24	28	2.86	98.18	9.34	89.83	13.70	82.17
28	32	1.18	99.36	5.37	95.20	9.35	91.62
32	35	.39	99.75	2.36	97.56	3.99	95.61
35	48	.24	99.99	1.59	99.15	2.83	98.34
48	---	.10	100.09	.92	100.07	1.64	99.98
Per cent in range through 12 on 35 (0.055 in. to 0.0164 in diameter)							
-----	---	---	50.67	---	76.11	---	89.14

	R. P. M.	Peripheral Velocity, ft./sec.
Lot 2.....	810	22.5
Lot 4.....	1,000	27.7
Lot 3.....	1,220	33.8

The upper peripheral edge of the spinning dish 2 is disposed substantially above the collecting pocket 14 in order that the shot will not build up directly opposite the point where it first enters the water. As shown in Figure 3, when the globules are thrown from the upper edge of the dish, they will travel in a substantially horizontal path and, as indicated in Figure 2, this path will be substantially tangential to the periphery of the dish. By providing the revolving container 3 for the water with its axis of rotation the same as that of the spinning dish 2, the inner surface W of the revolving wall of water becomes cylindrical and closely perpendicular to the direction from which the shot is cast from the spinning dish when the speed of rotation of the container

3 is above a certain minimum. This minimum speed is expressed by the formula:

$$N = 264.3 \sqrt{\frac{H}{R_T^2 - R_B^2}}$$

Where all units of measurement are in inches and:

N=R. P. M.

H=Maximum vertical height of liquid cooling medium

R_T =Radius of inner wall surface of liquid media at its top

R_B =Radius of inner wall surface of liquid media at its bottom.

Since the water wall is revolved substantially normal to the almost horizontal but slightly arcuate path of movement of the globules from the spinning dish into the wall of water, flattening of the globules upon striking the water is precluded. At the time the globules strike the water they are still in molten condition, but because the water is revolving and the globules are entering thereinto substantially normal to the surface of it, further spinning of the globules results and the tendency for them to flatten upon striking the water is overcome. Consequently, the spherical shape of the globules is maintained and they will, therefore, solidify into substantially spherical shot after entering the water. Also, because the surface W is substantially normal to the path of travel to the globules, the globules will enter into the water rather than glance off the surface thereof which would happen if the surface was not substantially normal to the path of travel of the globules.

By providing the wall of water with its inner cylindrical surface W positioned about the spinning dish and extending essentially vertically for some distance above and below the dish, the distance between the edge of the dish and the surface of the water can be regulated very closely and this distance can be very short. In this manner, the fine globules of metal enter the water almost instantaneously after being thrown from the periphery of the dish and, consequently, are given practically no opportunity to ignite or burn to metal oxide. The distance between the spinning dish and the water is such that the globules of metal will enter the water before they have solidified. This distance can be regulated merely by varying the amount of water in the container 3 after the container reaches a given minimum speed of rotation. Thus, to control this distance it is merely necessary to control one variable.

The wall of water must be of sufficient extent, in the direction of travel of the globules which enter thereinto, that the globules will be cooled by the liquid to the solidification point before they strike the angular wall 12a of the container. As the globules enter and pass through the water they traverse a lengthened arc-like path from their point of entry into the water. For this reason, a relatively small amount of water is required to obtain sufficient cooling of the shot particles before they hit the sloping wall 12a of the container. As a result, less water for cooling may be employed and, consequently, the apparatus will be less costly to operate because less power is required to rotate the container 3. The angularly disposed walls 12a and 13a are thus so disposed relative to each other that a minimum amount of water may be supplied and still the water will be of sufficient depth or extent in the direction of travel of the particles of metal. Thus,

the apparatus can be made much smaller than prior art apparatus.

Before the particles strike the sloping wall 12a, they are in solidified form, as previously indicated. The particles are quench-hardened during their passage through the water. When the particles do strike the wall 12a, they are moved by the action of centrifugal force against the container wall 12a downwardly into the pocket 14 where they are collected for removal. The angle of this wall 12a is preferably less than 45° from the horizontal to prevent bridging of the particles outwardly from the wall at a level substantially corresponding to that of the upper edge of the dish 2. This wall serves to direct the quenched shot out of the path of the incoming shot as well as to direct the shot into the pocket 14 from which it may be removed as a batch, at intervals along with the quenching medium, in the manner previously described.

It is apparent from the above description that I have provided an improved method for shotting metals which is performed in apparatus comprising a throwing dish, means for charging molten metal onto said rotating dish to be comminuted, and an annular rotatable container member disposed about said dish for retaining the cooling liquid, such container being provided with an outwardly sloping side wall disposed in line with the path of the shot thrown from the dish. The speed of rotation of the annular container, while containing the liquid cooling medium, will be such as to provide a liquid wall normal to the direction in which the shot is thrown. Furthermore, the wall of the container is provided with a pocket for collecting the shot.

By practicing the present invention, more uniform and more rapid cooling of the molten metal shot is provided. Furthermore, the apparatus for accomplishing my shotting method may be small as compared to the apparatus necessary for performing prior art processes. The particular construction of the apparatus which I use in performing my process collects the shot below the line of travel of the shot thrown from the dish. Consequently, piling up of shot against the wall of the annular container is prevented so that the extent of the water necessary to solidify the shot material is less, which results in longer cooling time and less danger of adherence of the shot particles to one another.

The relatively uniform and rapid rate of heat extraction from the metal particles, as is provided by the revolving water wall into which the particles are directly thrown, not only provides means of preventing the ignition and burning of steel droplets, as would occur in air, but also provides a uniform quench hardening for shotted plain carbon and low alloy steels. Thus, the process of this invention provides a hardened steel shot particle as-produced which needs no subsequent hardening, heat treatment to provide the hardness desired for shot particles for use in peening the surface of metal articles to improve their fatigue endurance and hence prolong their useful life.

Hardness determinations made on three lots of steel shot, produced by my process and having carbon contents of 0.42, 0.45 and 0.53% gave their average Rockwell C hardness as 59.5, 61.0 and 62.0, respectively. These hardness values are about the maximum hardnesses recognized as being obtainable for such carbon content steels. (See A. S. M. Trans., vol. 26, page 14, 1938.) Thus, it is evident that the cooling rate attained

for steel shot particles by the process of my invention exceeds the critical cooling velocity required for developing full hardness.

The commercially available prior art shot which has been used most widely during the development period of surface metal peening, and which industry desires to be replaced by a shot of improved toughness for longer and more efficient service life, is a white cast-iron shot. This iron shot may have sufficient hardness, but lacks in the needed toughness to keep it from readily fracturing and providing an abrading action in place of the desired peening action. Comparative breakdown tests of 0.40 per cent carbon steel shot of this invention in the "as-produced" hardened condition and the prior art white-iron shot were made in industrial blasting equipment. It was shown that this "as-produced" hardened steel shot had five to six times the life of the prior art white-iron shot. Another similar breakdown test using the steel shot after it had been given a low-temperature tempering treatment at 600° F., which is essentially the stress relief treatment given the prior art white-iron shot, and which reduced its hardness to 48 Rockwell C, showed a further marked superiority for the steel shot made by the process of my invention. It was found that this tempered steel product withstood 300 passes through the blasting equipment without an appreciable amount of the shot fracturing. This is to be contrasted to a breakage under the same condition of use of 55 per cent of the "as-produced" hardened steel shot in 65 passes, and a breakage of 70 per cent for the prior art white-iron shot in only 20 passes.

It can be stated, as a general rule, that the harder the metal to be peened, the higher is the hardness needed for the shot, and the more rapid will be the shot breakdown. Also, it is thought that no benefit is to be derived from a shot hardness more than 2 to 4 points Rockwell C higher than the work being peened. Since a hardened steel shot, such as producible by my improved shotting method, can be reduced readily in hardness to controlled levels by simple low-temperature tempering treatments, while the prior art white-iron shot cannot be so altered by low-temperature tempering, the desirability of having a method and apparatus for shotting steel in the manner of the present invention becomes evident.

There are many other industrial applications in which a fully hardened, or hardened and tempered, steel shot particle, made industrially available by the process of the present invention, is applicable and will be found more economically and technologically advantageous to use than the prior art white-iron shot which is more brittle and, hence, more readily fractured than the hardened steel shot.

Other metals than steel can likewise be shotted by the process of the present invention to provide a suitable shot particle media for surface peening machine parts made of other metals or alloys than steel. For example, it is desirable to have available a stainless-steel-base shot for blasting stainless steel; a copper-base alloy for blasting copper-base alloys, etc.

The present invention also provides a means for forming steel, copper, bronze, stainless type steel, Hadfield manganese steel, and other metals and alloys in a rounded shot particle form suitable for use in certain so-called "powder metallurgy" applications wherein small rounded particles of metal are applicable and in some in-

stances essential to provide a desired high porosity in the articles formed by powder metallurgy techniques.

Metal particles may be formed by the method of this invention which are in a suitable condition and particle size for further ready comminution by mechanical crushing means to grit, flake, or powder-like particles which find application in numerous industrial processes, among which is the powder metallurgy industry, which is relatively young and is rapidly expanding as to the number and types of metals and alloys adaptable in that industry and required in a finely comminuted form.

Having thus described my invention, what I claim is:

1. A method of forming solidified particles from molten material which comprises discharging the molten material in the form of a thin vertical stream upon a member rotating about a vertical axis which disintegrates the stream into globules and throws them outwardly substantially tangentially therefrom through the ambient atmosphere along a substantially horizontal path, said rotating member being disposed concentrically within an annular container containing quenching liquid for cooling said globules, rotating the container at a minimum speed expressed by the formula:

$$N=264.3\sqrt{\frac{H}{R_r^2-R_b^2}}$$

Where all units of measurement are in inches and

$N=R$. P. M.

H =Maximum vertical height of liquid cooling medium

R_r =Radius of inner wall surface of liquid media at its top

R_b =Radius of inner wall surface of liquid media at its bottom,

so that the liquid in the container will be in the form of an annular revolving body that has its inner surface substantially vertical, said rotating member being so located vertically relative to said body of liquid that the globules will enter said body intermediate the height thereof.

2. Apparatus for forming solidified particles from molten material comprising a member rotatable about a vertical axis upon which a stream of the molten material is discharged and which is adapted to disintegrate the stream into globules, a liquid container surrounding said member and adapted to contain quenching liquid for said globules, said container being rotatable about a vertical axis, means for rotating said member and said container, said container being provided with a guide wall including an outwardly and downwardly sloping guide section spaced from said member, said member being at a level substantially above the lower edge of said sloping guide section.

3. Apparatus according to claim 2 wherein said sloping guide section is disposed at an angle of less than 45° relative to the horizontal.

4. Apparatus for forming solidified particles from molten material comprising a member rotatable about a vertical axis upon which a stream of the molten material is discharged and which is adapted to disintegrate the stream into globules, said member being dish-shaped, a liquid container of annular cross section surrounding said member and adapted to contain quenching liquid for said globules, said container being rotatable about the vertical axis of said dish-shaped

member, means for rotating said dish-shaped member and said container, said dish-shaped member being spaced from the side wall of said container, said side wall including an outwardly and downwardly sloping guide section of substantially frusto-conical form, said section being disposed at an angle of less than 45° relative to the horizontal, said member being at a level substantially above the lower edge of said sloping guide section.

5. Apparatus according to claim 4 wherein said rotating means includes means for independently rotating said dish-shaped member and said container.

6. Apparatus for forming solidified particles from molten material comprising a member rotatable about a vertical axis upon which a stream of the molten material is discharged and which is adapted to disintegrate the stream into globules, said member being dish-shaped, a liquid container of annular cross-section surrounding said member and adapted to contain quenching liquid for said globules, said container being rotatable about the vertical axis of said dish-shaped member, means for rotating said dish-shaped member and said container, said dish-shaped member being spaced from the side wall of said container, said side wall of said container being formed by an upper guide section of frusto-conical form which is at an angle of less than 45° relative to the horizontal, and an inverted frusto-conical section joining the upper section to form a particle collecting pocket, said pocket being located below the level of said dish-shaped member.

7. Apparatus for forming solidified particles from molten material comprising a member rotatable about a vertical axis upon which a stream of the molten material is discharged and which is adapted to disintegrate the stream into globules, said member being dish-shaped, a liquid container of annular cross-section surrounding said member and adapted to contain quenching liquid for said globules, said container being rotatable about the vertical axis of said dish-shaped member, means for rotating said dish-shaped member and said container, said dish-shaped member being spaced from the side wall of said container, said side wall of said container being formed by an upper guide section of frusto-conical form and an inverted frusto-conical section joining the upper section to form a particle collecting pocket, said pocket being located below the level of said dish-shaped member, said lower section extending to the bottom of the container, said bottom of the container being provided with discharge apertures.

8. Apparatus according to claim 7 wherein said upper guide section is at an angle of less than 45° relative to the horizontal.

9. A method according to claim 1 wherein the rotating member is dish-shaped in order to exert a retarding action on the molten material so as to ensure formation of the molten material into globules before leaving such member.

10. A method according to claim 1 wherein the distance through which said globules travel in the atmosphere before striking said revolving body of liquid is such that oxidation of the globules before striking the liquid is precluded and such that the globules will be molten when they strike the liquid.

11. A method according to claim 1 wherein the rotating member is dish-shaped in order to exert a retarding action on the molten material so as

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to ensure formation of the molten material into globules before leaving such member, and wherein the distance through which said globules travel in the atmosphere before striking said revolving body of liquid is such that oxidation of the globules before striking the liquid is precluded and such that the globules will be molten when they strike the liquid.

12. A method according to claim 11 wherein the body of liquid is of sufficient extent in the direction of travel of said globules therethrough that the globules will be solidified completely before striking the outer wall of the container.

13. A method according to claim 1 wherein the molten material discharged upon the rotating member is at a temperature approximately 200° F.

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to 250° F. above the liquidus temperature of such material.

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