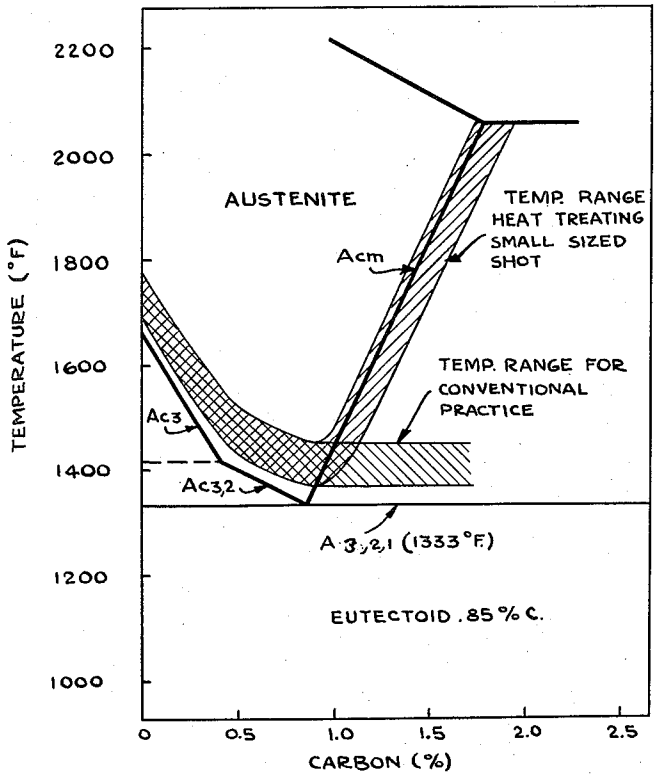
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METHOD OF MAKING STEEL SHOT

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METHOD OF MAKING STEEL SHOT

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This invention relates to steel shot for use in blast cleaning, peening, polishing and the like and to a method for making said steel shot.

Metallic shot for use in blast cleaning, peening or surface treating operations should be very small in size, be hard enough to properly clean or peen the work and it should have long life for resistance to fracture when repeatedly impacted against a surface. The first of these characteristics—namely, metallic shot may vary in sizes between approximately 0.005" diameter and 0.10" diameter and can be made by one of several disintegration methods already known to those skilled in the art.

In these disintegration methods a stream of molten metal, usually iron, is hit by a stream of water from a nozzle or projected by a centrifugal throwing wheel. The molten metal is disintegrated and flies through the air forming shot which is then caught in a pond of water, dried and graded into several different sizes of shot.

It is relatively easy to make shot from iron by disintegrating methods so iron shot has been used in the blast cleaning industry for many years. It has long been known that steel has inherent characteristics which should be better than those of iron for a shot to be used in blast cleaning or peening. The technical problems of producing a steel shot have been so great that only in the last few years has anyone attempted to produce a steel shot commercially. The steel shot produced heretofore has not been as of high quality as was desired.

The problem is that medium and high carbon steels are required in order to obtain good hardenability and when these steels are disintegrated they commonly form shot, a large percentage of which will be either hollow, shredded or non-round, or shot having small surface quench cracks. Each of these defects causes the shot to have a short life or have poor resistance to breakdown in service. Experience in blast cleaning and peening operations has taught that the ideal shot would be that wherein each shot is a solid round ball of steel free from surface quench cracks and which has a tempered martensite micro-structure giving it a hardness of approximately 40 to 50 Rockwell C.

In an effort to closely approach this ideal the discovery was made that an unusual chemical analysis for the steel must be used; that closely controlled melting, pouring and shotting technique must be followed and an unusual heat treating procedure must be used to obtain optimum results. Some of the practices followed under this invention are exactly the opposite of what normally would be considered the proper practice for making a sound and crack-free steel casting.

As will be disclosed in detail later in this specification, the following points are typical of those where this invention deviates and is contrary to conventional practice.

(1) The silicon content of the steel must be considerably higher than that normally used in plain carbon steels, yet it must be lower than that contained in the so-called silicon steels.

(2) The manganese content of the steel must be considerably higher than that normally used in ordinary carbon steels, yet it is lower than that contained in the so-called manganese steels.

(3) The carbon content must be greater than 1.15%, yet it should not exceed 1.40%.

(4) Even though a tempered martensite micro-structure is desired in the finished product, formation of martensite in the as-cast shot must be avoided. The shot first formed from the disintegration of molten steel must have predominantly an austenitic micro-structure and in later heat treating operations it can be transformed from austenite to martensite and finally to tempered martensite.

(5) The heat treating temperature must be higher than that normally used for steel of the same carbon content.

In carrying out this invention, the steel is suitably melted in a high temperature melting furnace, such as an electric arc furnace, by the open bath or total oxidizing method. An initial charge of steel scrap is first melted down after which ore, i. e., iron oxide is added to obtain an oxidized state which is maintained throughout the heat.

This iron ore may be added to the bath at any time before the bath reaches approximately 2500 to 2600 deg. F. The silicon combines with the oxygen to form silicon oxide which floats to the slag, thus decreasing the silicon content of the bath to 0.10% and lower, at the end of the boil as described below.

When the temperature of the bath reaches approximately 2700 to 2750 deg. F. there is a reaction between the carbon and iron oxide forming in turn carbon monoxide and then carbon dioxide, this reaction producing a boil or agitation, such as occurring when water boils. If the residual silicon and manganese contents are low, this boil may take place at a lower temperature. This boil provides a carrying or cleansing action for the bath, removing approximately all of the entrapped gases and metal oxide inclusions and producing a very fluid metal with high surface tension.

After the metal is boiled to remove the gaseous and oxide inclusions as above stated, the bath is subjected to a refining period during which the composition of the slag is controlled by the addition of ferro-manganese, mill scale, burned lime, fluor-spar, etc., in the case of basic furnaces, or ferro-manganese, mill scale, silica sand, lime, etc., in the case of acid furnaces. These agents are added in such amounts as are necessary to impart to the slag a black shiny color when sampled by the slag pancake method in the case of basic furnaces or a pea green color when sampled by the slag fracture method in the case of acid furnaces. Also, such slag tests as fluidity or specific gravity may be used.

When the bath reaches the pouring temperature, which may be anywhere between 2900 and 3200 deg. F., the alloying ingredients are added for the purposes of alloying the bath to the final desired composition, this alloying process also acting to deoxidize the bath. Besides the addition of ferro-silicon and ferro-manganese a strong deoxidizing agent such as calcium, silicon, manganese, aluminum, titanium, etc. should be added.

It is necessary that the furnace be kept completely in the oxidized state throughout the entire heat up to the time of final alloying just before pouring. If a reducing condition exists in the furnace, especially toward the end of a heat, but before final alloying, non round material will be made.

It is also important that the silicon be oxidized to a point below 0.10% and kept there until the final silicon alloying, since otherwise the shot will tend to be hollow due to nitrogen, hydrogen and other gas content. Silicon acts as holding agent for these gases, and unless re-

moved, these gases will cause the formation of hollow shot.

The boiling period is necessary to remove entrapped gases and entrapped slag, resulting from the oxidation of the oxidizable elements such as silicon, manganese, chromium, vanadium, etc. These elements combine with oxygen to form slag inclusions which, without boiling, tend to remain in the bath during the pouring and disintegrating, becoming located in the cast shot and tending to cause weak spots in the shot.

It is important that the bath be completely deoxidized at the very end of the heat just prior to pouring. Silicon will deoxidize the bath to a certain extent, but as silicon does not remove completely all the oxygen resulting from the addition of iron oxide, it is necessary to use stronger deoxidizers such as aluminum, calcium-silicon-manganese, titanium, vanadium, etc. for this removal of oxygen.

The molten metal is preferably disintegrated by the method of disintegration disclosed and claimed in U. S. Patent No. 2,563,064 issued to Otto A. Pfaff. In this method the molten metal passes through a refractory orifice of rectangular cross section and falls vertically in a ribbon shaped stream.

The disintegrating blast of water is discharged in a controlled direction by a centrifugal throwing wheel against the flat side of the molten metal stream. The centrifugal wheel is in a vertical plane which passes through the molten metal stream as it falls through the refractory orifice. As the water is directionally discharged from each blade it bombards the molten metal stream with a rapid succession of layers of water forming a pulsating type flow which disintegrates the molten stream into metal particles.

Disintegration of the molten stream of metal also can be accomplished by other methods such as directing a solid stream of water from a nozzle against the falling stream of metal but this method is not as efficient.

The disintegrated molten particles of steel are caught in a pond or bath of water where they solidify. This gives what is sometimes hereinafter referred to as the "initial" quench.

The entire disintegrating apparatus and pond may be surrounded with an enclosed cabinet which is filled with an inert gas such as nitrogen. Such an enclosure helps prevent burning of the small steel pellets, oxidation of the elements such as silicon and manganese, and decarburization of the surface of the steel during the disintegration method. However, good steel shot has been made by the method described herein without the use of an inert atmosphere. If the pond is enclosed, water vapor and steam formed in the operation help prevent air from contacting the shot during the disintegrating operation. Additional silicon and manganese can be added to the melt to compensate for any burned out during the shotting operation. Any surface decarburization of the shot is largely overcome by recarburization during subsequent heat treating procedure as explained below.

The shot is preferably initially quenched after disintegrating by catching it in a pond containing water warmer than room temperature or in a slower quenching medium such as a mixture of water and soluble oil. Using a mild quench medium minimizes a tendency for small surface cracks to develop on the shot during the initial quench. It also gives better roundness of the shot since heat is removed from the ball more slowly and more time is available for surface tension to draw the metal into a ball before solidification. Best results were obtained with water having a temperature of 120 to 160 degrees F. When the subsequent heats are disintegrated into the same pond and the water temperature starts to exceed 160 degrees F., the water should be cooled, otherwise, non-round and hollow shot may be formed. Initial heating of the water can be accomplished by use of immersion heaters. Subsequent cooling can be accomplished by draining off warm water and adding cool water or by means of a cooling tower.

Heat treatment of the shot is preferably done in a rotary retort type furnace where the retort rotates on its longitudinal axis and in a horizontal plane. The retort is only partially filled with shot so that as the retort rotates, the shot is in constant agitation as it tumbles wihin the retort. This tumbling action insures better heat transfer, more uniformity of heating and reduces the tendency of one pellet of shot to stick to another.

During the heating cycle, raw natural gas or other carburizing type gas can be fed into the retort so that the shot is protected from air. This also helps to overcome any surface decarburization of the steel shot which may have occurred during the disintegrating operation by the recarburization effect during this heat treatment.

It is very important that the alloying ingredients of the steel be held to close limits. Silicon content preferably should be between 0.65 and 0.75% but in no case should it be allowed to exceed 0.90% or drop below 0.40%. When the silicon exceeds 0.90% the particles of steel formed after disintegration are apt to be shredded. On the other hand, silicon contents in the normal range for plain carbon steels such as those below 0.40% silicon produce round steel shot but the shot contains many hollows instead of being solid balls. These hollow balls break easily in blasting operations and therefore are undesirable.

Although steel shot has been made which has a wide variation in carbon content, in accordance with this invention it was learned that for optimum results the carbon must be held to very close limits. The preferred carbon content is between 1.25 and 1.35% but it can be as low as 1.20% carbon or as high as 1.40% carbon.

Carbon content is particularly important because of its effect on the tendency for small surface cracks to form on the steel shot during the initial quench of the molten shot during disintegration. Initially it was thought that steel shot made using approximately eutectoid steel or one having approximately 0.85% carbon would be best. This steel gave a round and solid shot with martensitic micro-structure but formation of small surface cracks on the shot could not be avoided even when the shot was initially quenched in warm water.

Contrary to expectations, it was discovered that to eliminate surface cracks it was necessary to increase the carbon content appreciably rather than reducing the carbon content. Common metallurgical practice is to reduce the carbon content when a cracking tendency exists in castings or forgings. Apparently shot, because of its very small size, behaves differently than castings or forgings of larger size.

Experimental heats were run covering a wide range of carbon contents with careful exploration of various carbon ranges from 0.70 to 1.50% carbon inclusive. The very best shot in the as-cast condition from a crack-free standpoint was found to be 1.50% carbon and the poorest was found to be in the 0.70 to 0.85% carbon range. Micro-examination of the shot disclosed that it was the formation of martensite during the initial quench that was causing the surface cracks.

For example, shot having a carbon content of 0.77% contained more than 95% martensite with less than 5% retained austenite and this shot had many surface cracks. Eutectoid steel or 0.85% carbon contained approximately 95% martensite and 5% retained austenite and was badly cracked. Steel with 1.50% carbon contained only about 10% martensite and 90% retained austenite. This shot was practically free from cracks. As the carbon was lowered from 1.50% to 1.20% a proportionately greater amount of martensite was formed during the initial quench and the tendency to form cracks was increased but reasonably crack-free shot was made from 1.20% carbon steel.

The conventional practice of heat treating carbon steel

as is normally practiced by foundries and forge shops is to austenize steel of lower carbon content at higher temperatures and vice versa. An example is given in the following tabulation, summarized from the 1948 Metals Handbook, pages 631 and 660.

Type of Steel (A. I. S. I.)	Carbon Range (in Percent)	Hardening Temp. Range (° F.)
1010, 1015	.18-.18	1, 650–1, 700
1020, 1025	.18-.28	1, 600–1, 675
1030	.28-.34	1, 575–1, 650
1035	.32-.38	1, 525–1, 600
1040	.37-.44	1, 500–1, 575
1045, 1050	.43-.55	1, 475–1, 550
	.60-.80	1, 450–1, 550
	.85-1.05	1, 425–1, 550
	1.10-1.40	1, 400–1, 525

However, for very small particles of steel shot it was found best to depart from conventional practice and to heat treat the shot at higher temperatures as the carbon content was increased. Since carbon contents of less than 1.20% were found undesirable from a surface cracking standpoint as explained above, only the range of 1.20% to 1.50% carbon will be considered. Best results were obtained when steel of such carbon content was heat treated at a temperature close to the A*cm* line on the iron-carbon diagram rather than the conventional practice of using a temperature near the Ac**321** line as illustrated by the accompanying drawing.

Heat treating at a temperature near the A*cm* line on the attached iron-carbon diagram normally is not practiced because it causes grain growth. In the case of the very small size shot, grain growth is not nearly as serious from the standpoint of long life or resistance to fracture as were undissolved carbides which caused brittleness. Best results for steel shot are obtained when the temperature was increased with increasing carbon content so as to stay just under the A*cm* line on the iron-carbon diagram. Thus, for a 1.50% carbon steel the preferred heat treatment would be approximately 1800 degrees F. and for a 1.30% carbon steel it would be approximately 1700 degrees F. except for a practical problem as noted below.

Whenever the temperature exceeded approximately 1700 degrees F., small size shot even when agitated in a rotary retort furnace would stick together and form agglomerates which could not be used. It is believed this is due to small particles of scale softening under this temperature and acting as a flux to weld one small particle of steel shot to another. It was found that small sized steel shot could be heat treated without formation of agglomerates at a temperature of 1700 degrees F. A 1.50% carbon steel shot heat treated at this 1700 degrees F. temperature had too many undissolved carbides and was brittle. By lowering the carbon content toward the 1.20% carbon limit and staying under 1.40% carbon it was possible to heat treat the steel shot at approximately 1700 degrees F. and have most of the carbides dissolved.

Because of the small thermal gradient between the surface and the core of small sized shot during heat treatment, the small amount of undissolved carbides is well dispersed and does not link up in segregated areas to form lines of brittleness. Since the undissolved carbides are extremely hard, the presence of them in small and well dispersed quantities is desirable because such shot will clean better in blasting operations.

After the shot has been quenched in warm water or other mild quench medium from 1700 degrees F. it is placed in the retort of a second heat treat furnace where it is drawn at approximately 1000 degrees F. depending on the hardness of shot desired. Hardnesses between 35 and 55 Rockwell C were found to be best from the standpoint of cleaning or peening ability and long life. After the double heat treatment mentioned above the steel shot has a tempered martensite micro-structure.

It is also important that the manganese content be held to close limit in a range higher than normal for plain carbon type steels. The preferred range is 1.15 to 1.25% but it can be anywhere between 1.00 and 1.50% manganese. Manganese not only serves to produce a stronger steel but it also has the same general effect as carbon in reducing any tendency for the shot to have surface cracks. As manganese content is raised above 1.00% the amount of martensite formed during the initial quench is reduced and surface cracking tendency is reduced. In this respect manganese has less effect than a similar increase in carbon content. Since it is relatively expensive the preferred manganese content is in the lower half of the 1.00 to 1.50 range but a manganese content in the upper half of the range will work equally as well.

Appreciably higher manganese contents tend to produce stringy or shredded shot. Steel shot also was made using other alloying agents such as chromium, molybdenum, vanadium, nickel and copper but these are not necessary to produce a good round and solid shot reasonably free from surface cracks and hollows which shot has very long life. If such alloying agents are used, it has been found that the following range of amounts is most desirable; 0–5.% chromium, 0.4% vanadium, 0–2.5% nickel, and 0–1.0% copper.

While certain novel features of the invention have been disclosed herein, and are pointed out in the annexed claims, it will be understood that various omissions, substitutions and changes may be made by those skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. The method of making round and solid steel shot reasonably free from cracks and hollows and containing carbon, manganese, silicon, and iron, which comprises melting the above materials in an open bath furnace while it is in an oxidized state throughout the heat, boiling the molten bath at a temperature of approximately 2700–2750° F. to remove gases and inclusions of metallic oxides, maintaining the silicon content below 0.10% until the final silicon alloying, controlling the composition of the slag, deoxidizing the bath and alloying the bath to 1.20 to 1.40% carbon, 1.00 to 1.50% manganese and 0.40 to 0.90% silicon then adding at least one strengthening alloy metal selected from the group consisting of chromium not exceeding 5.0%, molybdenum not exceeding 5.0%, vanadium not exceeding 0.4%, nickel not exceeding 2.5%, and copper not exceeding 1.0% and the balance substantially iron, pouring the metal, disintegrating it into particles of less than 0.1" diameter, initially quenching the disintegrated particles in a mild quenching medium, drying the disintegrated particles, and then heat treating the particles at a temperature close to the Acm line on the FeC diagram, to produce a tempered martensite micro-structure.

2. The method of making steel shot according to claim 1 in which the shot particles are heat treated at a temperature of 1650° to 1750° F., excluding air from the heat treat during this heating period, quenching the shot particles in a mild quench medium, then heat treating the shot particles at approximately 1000° F., to produce a hardness as desired from approximately 35 to 55 Rockwell C., and allowing the shot particles to cool in air.

3. The method of making steel shot according to claim 1 in which the disintegrated particles are initially quenched in water at a temperature of 120° to 160° F.

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