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BORON SHOT
GRADING AND
INSPECTING

BDX-613-155

September, 1970

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KANSAS CITY, MISSOURI

A prime contractor for the Atomic Energy Commission

Contract Number AT(29-1)-613 USAEC

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ABSTRACT

An inspection system for grading development quantities of boron shot has been developed. A wire-mesh sieving process is used to size the shot. Compressive strength and chemical composition is determined by standard laboratory techniques.

CONTENTS

Section		Page
1	SUMMARY	1
2	DISCUSSION	2
	SIZE	2
	SPHERICITY	3
	DENSITY	5
	COMPRESSIVE STRENGTH TESTING	6
	CHEMICAL COMPOSITION TESTS	6
	PROPOSED CONTINUOUS-FEED SHOT GRADER	6

ILLUSTRATIONS

Figure		Page
1	Vibratory Drive Principle	4
2	Top View of Vibratory Roundness Sorter	4
3	Non-Vibrating Variation of Basic Sorter	4
4	Shot Fragments at 47X (Polaroid)	7
5	Semi-Automatic Shot Grading Sorter Schematic	7

Section 1

SUMMARY

An inspection system for grading development quantities of boron shot has been developed. The original requirement was to develop methods that would be satisfactory for processing up to 10 pounds of ungraded shot (approximately 55,000,000 pieces at 0.015 ± 0.005 inch diameter) per day. Product acceptance standards demanded that 100 percent of the shot be graded for diameter, roundness and density; spot checks for chemical composition, compressive strength and surface finish were also required.

Activity was initiated early in 1969 to develop a method of fabricating and inspecting boron shot. A shot tower method of producing the required shot was investigated and has been reported on.

A wire-mesh sieving process is sufficient for sizing the shot, and a liquid flotation test satisfies the requirements for density inspection. Acquiring a roundness grader was difficult, but a system using a vibrating inclined steel plate proved to be adequate for the roundness checks conducted. Compressive strength and chemical composition were determined by standard laboratory testing techniques. Surface finish inspection was limited to microscopic examination of the shot.

Additional refinement of the roundness grader is required, especially as related to separating rollable, non-round, egg-shaped particles from the desired spherical particles. A continuous-feed sieving process would be preferable to the present low-capacity batch process.

The boron shot production and inspection projects were prematurely terminated because the primary need for the shot did not materialize.

Section 2

DISCUSSION

Difficulties encountered during the shot fabrication study prevented the production of more than several grams of shot per day; therefore, the shot grading system was not tested with large quantities of material. Nevertheless, this grading system should be readily adaptable to the processing of 10 pounds of shot per day, the original target amount.

At the time activity was terminated, product definition was that the shot be 0.015 ± 0.005 inch in diameter, have a high degree of "rollability" and possess a "high" crush strength. Density and chemical composition were important only to the degree that the crush strength of the shot would remain high. The basic grading system that was adopted provided for diameter, density and sphericity inspection of the entire output from the shot tower. Spot checks of crush strength and chemical composition were performed using standard techniques.

SIZE

The grading procedure for size separation used standard 8-inch diameter brass-framed sieves. These sieves "nest" one atop the other and allow as many "mesh cuts" as desired. For this project the mesh sizes used were no. 60 (0.0098 inch), no. 45 (0.0139 inch), no. 40 (0.0165 inch), and no. 35 (0.0197 inch).

For optimum accuracy of sizing, the stack of sieves should be shaken by a mechanical shaker that imparts a rotational and tapping motion to the sieves. These sieves are primarily a laboratory tool and, as such, have a capacity of about one pound of shot per loading. They have the disadvantage of being a batch process rather than a continuous-feed process.

Large motor-driven continuous-feed screens are available that have capacities ranging from pounds to tons per day. A system that was not tested but appears ideal for a "table top" continuous-feed screening process uses the vibratory drive principle to move "over-mesh" size particles across the screen from one end to the other and subsequently into a bin at the end of the screen. "Under-mesh" size particles fall through the screen and are routed to the next smaller screen in the series.

The major screening difficulty encountered was that of "blinding" of the screens by "near-mesh" size particles. Non-round, jagged particles were the worst offenders; consequently, roundness grading always

preceded sieving. Those particles that still stuck in the screen were most readily removed by gentle tapping on the inverted screen, although a compressed air blast may also be used to clear the screen. Care must be exercised to prevent excessive wear of the screen, since boron is extremely hard (9.7 mohs) and abrasive.

SPHERICITY

The roundness requirement specified for the shot was that the particles have a high degree of "rollability." A Syntron vibrating feeder drive unit was most suitable for efficient sorting. A 10- by 12-inch steel plate affixed to the drive unit served as the "roll plate" for the shot.

The vibratory drive principle is illustrated in Figures 1 and 2. The particles are actually thrown across the drive plate in a series of short arcs. Drive frequency is usually 3600 Hz.

For roundness sorting, the drive table is slightly tilted about an axis which is parallel to the direction of vibratory flow. As a result, round particles readily roll off to the side of the plate and non-round particles are vibrated towards the end of the plate.

Best roundness grading was achieved by making at least three passes across the sorter table. On the first pass, the vibratory drive was set at a high amplitude and the roll plate at a relatively steep incline of 15° to 25°. This coarse separation removed only very non-round particles such as flakes and jagged chunks of material. For each successive pass, the vibratory amplitude and plate angle were decreased for finer sorting; roll plate inclines were typically decreased in increments of about 5°.

A problem that was not entirely resolved was that of separating spherical particles from elongated, egg-shaped particles. These elongated particles usually rolled down the incline plate almost as readily as the spheres. A process that was given very limited testing but appears promising for removal of these odd shaped particles is a variation of the basic sorter. A batch of "rollable" particles are fed from a vibratory feeder and dribbled onto the end of a flat, inclined plane (Figure 3). The spheres roll in a reasonably straight line to the end of the plate and the other particles usually roll off the side of the plate. The trapezoidal-shaped plate is not vibrated.

Figure 1. Vibratory Drive Principle

Figure 2. Top View of Vibratory Roundness Sorter

Figure 3. Non-Vibrating Variation of Basic Sorter

DENSITY

The density test for boron shot was defined by the Bendix Test Laboratory and provided a simple procedure for examining all the shot product for undesirable internal voids. A flotation method was developed that would separate the shot into two fractions--one greater than 2.30 grams/cubic centimeter (98 percent theoretical density of crystalline boron) and the other less than 2.30 grams/cubic centimeter.

The flotation liquid used in these separations was obtained by mixing two miscible liquids of known density. Assuming a linear density relationship, the volume of one of the constituent liquids was calculated by assigning an arbitrary value for the volume of the other liquid in the equation:

$$2.953x + 1.594y = 2.30 (x + y),$$

where: 2.953 = Specific gravity of 1, 1, 2, 2 Tetrabromoethane;
1.594 = Specific gravity of Carbon Tetrachloride;
2.30 = Specific gravity of the flotation mixture;
x = Volume of 1, 1, 2, 2 Tetrabromoethane in ml; and
y = Volume of Carbon Tetrachloride in ml.

A check of the flotation liquid's density at 20°C was made by placing a sample of the liquid in a covered test tube suspended in a closely regulated constant temperature bath. Small samples of crystalline boron (density = 2.34 gm/cc at 20°C), and $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (density = 2.284 gm/cc at 20°C), were placed in the liquid. The boron was observed to sink to the bottom of the test tube while the copper sulfate was observed to float on the surface of the liquid. Thus, the density of the flotation liquid, (theoretical density = 2.30 gm/cc at 20°C), lies between these values whose differences is only 0.076 gm/cc.

The samples of boron shot were first weighed, then immersed in the flotation liquid in separate covered test tubes. The tubes were suspended in the constant temperature bath and allowed to stand overnight. The fraction floating in each test tube was then removed using a medicine dropper and gentle suction. After removal of the floating fractions, the sinking fractions were separated from the liquid by filtration, washed, dried and weighed. The floating fractions were then calculated by difference.

COMPRESSIVE STRENGTH TESTING

The test for compressive strength was performed using an Instron compressive strength tester. Carbide face plates were placed on the tester anvils and adhesive cellophane tape placed, adhesive face up, on the lower anvil. The individual pieces of shot were then placed on the tape and crushed. This method prevented the shot from rolling off the anvil and preserved the shot fragments for microscopic inspection. (See Figure 4.)

CHEMICAL COMPOSITION TESTS

Chemical composition tests were made to determine iron and carbon content. These two elements are the major impurities in the elemental boron and resultant shot. Carbon content was determined by a combustion technique; atomic absorption techniques were used to find the iron content.

PROPOSED CONTINUOUS-FEED SHOT GRADER

Figure 5 is a schematic of a semi-automatic grading system which should be investigated if this project is reactivated. Vibrating-plate roundness graders numbers 1 and 2 sort out non-rollable material and feed the remaining rollable particles to the sieve series. The sieves, of the continuous-feed vibrating-screen design, cull out all but the desired diameter range of shot. Roundness grader number 3 is a trapezoidal non-vibrating plate design that separates spherical particles from rollable non-spherical particles.

Figure 4. Shot Fragments at 47X

Figure 5. Semi-Automatic Shot Grading Sorter Schematic