71028

Usefulness, Effectiveness, and Process Technology of Glass Bead Shot Peening

By Gerald P. Balcar, and W. Earl Hanley
Potters Industries, Inc. and The Ballotini Group, S.A.

Steel shot peening as a means of developing substantially increased fatigue resistance through the creation of a layer of residual compressive stress on high performance alloys of steel, aluminum and titanium was introduced in the 1930's by Almen, Fuchs, Matteson, Straub, and others.[1] Specific application of the process to the aircraft industry, and its importance as a means of preventing stress corrosion has been reported by Moore, Kurz, Suess, Noble, and others.[2] The purpose of this article is to up-date the knowledge of the use of glass beads as a shot peening media with advantages they may offer to increase design capability and to develop more economical peening processing.

It was Noble[3] who first proved the value of glass beads as a shot peening media with two specific advantages. He used them at a variety of intensities on aluminum surfaces to avoid the necessary passivation or processing required to remove the contamination of steel shot, and he established that glass beads could be used to peen relatively delicate parts of narrow dimensions or with fillet areas of narrow radii with maximum control of results. He demonstrated that glass beads could serve as a shot peening media quite different in characteristics from the traditional steel shot.

Figure 1 is a simple comparison of the chemical and physical properties of glass beads vs. steel shot, which may be the first indication of their usefulness as a peening media.

In terms of density, soda lime type glass is normally 2.5 grams per cubic centimeter vs. steel with 7.2 grams per cubic centimeter. Useful intensities can be obtained with glass beads since beads, being lighter, accelerate to higher velocities.

When you compare chemical characteristics, you find steel is reactive in conventional corrosive environments while glass is virtually inert, reacting readily only with hydrofluoric acid as indicated. In applications involving aluminum by using glass bead peening to avoid passivation, there can be significant cost-savings.

Normally, pre-blasting is not necessary to insure adequate uniformity of total mass and fracture resistance of shot material. The smaller sizes and lower density of glass beads make possible their use in peening cutting tools, punches, and other sharp-edged surfaces which, in certain circumstances, can increase tool life.[4] Further, their lower density is easier to control at low intensities and is insurance against overpeening.

COMPARISON OF CHEMICAL & PHYSICAL PROPERTIES

Figure 1

	Glass Beads	Steel Shot
Hardness	Rockwell C 46-48	Rockwell C 40-50
Specific Gravity (gm/cc^3)	2.45-2.55	7.0-7.2
Chemical durability	in N.50 H_2SO_4 at 90°, 24 hrs. max. .03% extracted	reacts readily into oxides, sulfides, halides etc. and with acids.
Max. size in commercial stock	approx. 5-6 mm.	3-4 mm.
Min. size in commercial stock	20-40 microns	110-130 microns.

GLASS BEAD PEENING INTENSITIES

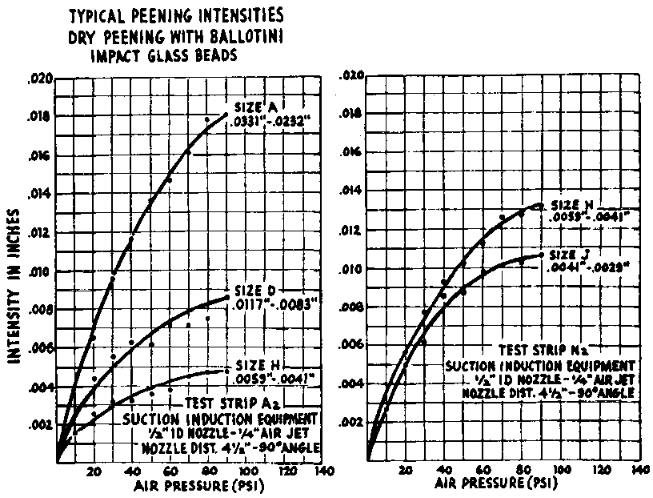
Matteson[5] with the objective of showing the saturation intensities that might be achieved in shot peening in favorable circumstances, used a ¼ in. direct pressure straight bore nozzle and a suction-induction system with a ½ in. nozzle and ¼ in. air jet.

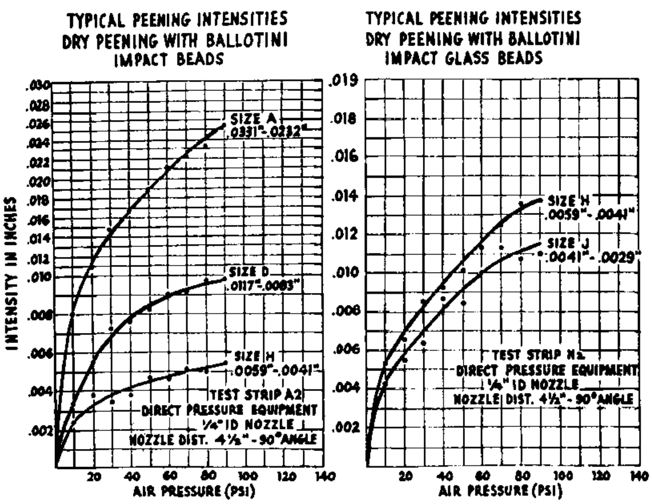
Figures 2 and 2A show the intensities which have been obtained with various diameters of beads with the suction-induction system. *Figures 3 and 3A* those which were achieved with the direct pressure system.

Figure 4 is a table for comparison listing and of the nominal masses and the range of masses of the nominal particle sizes. Ritter[6] prepared this information and it serves as a background to the effects of the two exponential functions that come to bear in shot peening. Of course, the function I or K equals $\frac{MV^2}{2}$ is fundamental. It is, however, important to note that

← For further information circle No. 2

M = 4/3 π R^3 x 2.5 or the specific gravity in gm/cc^3. The variance between the weight of the individual particles or each nominal range serves to show the ef-





fect of the exponents to the 3rd power on the mass of particles and thereby on the peening intensity which is obtained.

Once again, it should be emphasized that the purpose of these tests were to generalize the peening intensities that could be obtained with glass beads to provide guidelines for testing of specific machines or applications. It should be noted that similar nozzle and air jet sizes would be necessary to duplicate these intensities.

GLASS BEAD PEENING RESULTS

Noble[7] reports a series of tests showing the results of glass bead peening at various intensities on surfaces of various hardnesses.

Figure 5 demonstrates the depth of residual compressive stress after peening with glass beads nominally .015 ins. (380 microns) in diameter. This was done by determining arc and stress characteristics of samples after the removal of gradients from the surface by etching. The hardnesses shown are RC 40 and 60. The arc heights are .022N and .018N. These curves are known as "typical stress gradients."

Figure 6 is a stress gradient on a Rockwell C 40 sur-

Figure 4

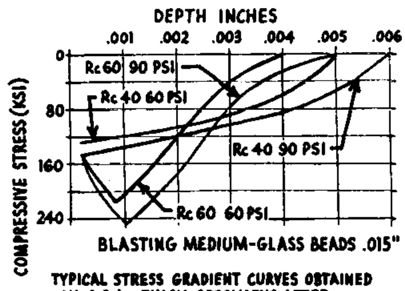
COMPARISON OF NOMINAL SIZE RANGES OF GLASS BEADS

SIZE	US. Sieve	INCHES	MICRONS	WEIGHT micrograms	COUNT Beads per lb. in millions
A	20-30	.0331-.0234	841-595	272-765	.99
B	30-40	.0234-.0165	595-420	96-272	2.8
C	40-60	.0165-.0098	420-250	20-96	13.4
D	50-70	.0117-.0083	297-210	12-33	22.4
E	60-80	.0098-.0070	250-177	7.2-20	37.7
F	70-100	.0083-.0059	210-149	4.2-12	63
G	80-120	.0070-.0049	177-125	2.5-7.2	106
H	100-140	.0059-.0041	149-105	1.5-4.2	180
I	120-170	.0049-.0035	125-88	.89-2.5	302
J	140-200	.0041-.0029	105-74	.53-1.5	514
K	170-230	.0035-.0025	88-63	.32-.89	864

face. This indicates the depth of stress achieved at the indicated intensities.

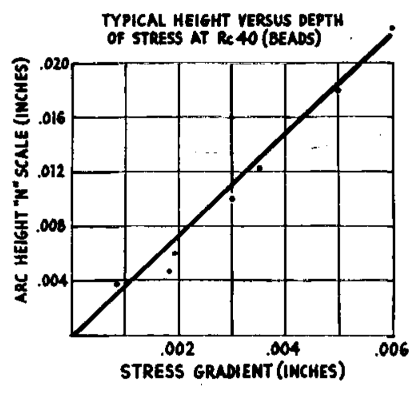
ECONOMICS OF GLASS BEAD PEENING

Because of the material characteristics of glass, impact consumption is a consideration in the use of glass bead



TYPICAL STRESS GRADIENT CURVES OBTAINED ON 0.2 in. THICK SPECIMENS AFTER BLASTING 10 SEC.

peening. We conducted tests from our own protocol to determine the nature of this impact consumption and to measure it as accurately as possible. In preparing the protocol it was necessary to consider the variables which, in this case, are three dimensional. First, the specific almen peening intensity; second, the size of glass bead material being used (i.e. diameter or mass); third, the hardness of surface. A fourth variable exists in the nozzle angle which we have studied in isolated tests. Indications are that impact consumption may be reduced by use of a reflecting nozzle angle which will reduce the possibility of glass impacting on glass through



reflection of glass particles back into the nozzle stream.

In order to reduce the complexity of the testing we adopted the 90 degree angle as being the one most acceptable in shot peening processes.

To establish a universal quantity of impact consumption we adopted the term "percent per cycle" which is a figure that can be multiplied by any feed rate to create an estimated consumption. To illustrate how we arrive at the "percent per cycle" take a flow rate of 100 lbs. per hour through a nozzle with a percent per cycle consumption of 3 percent, the consumption would be 3 lbs. per hour. If the flow rate is 500 lbs. in a multi-nozzle machine the "percent per cycle" consumption would then account for a use of 15 lbs. per hour.

The tests were based on blasting in specific conditions with carefully controlled cycles. Consumption was defined as the increase of material passing the bottom screen of the nominal size range or the increase in material that was smaller than the smallest screen opening of the nominal size range.

Testing of particle size before and after blasting was controlled. Samples were carefully slit with Tyler 16 to 1 or 1 to 1 sample reducers according to the methods which give a statistically representative sample. All size testing was done in duplicate. Consumption testing was also done in duplicate and the results averaged. Following the test all material was withdrawn from the generator and the dust bags were cleaned with the material in them added to the test charge. Any loss or gain in material was recorded and calculated into the findings. *Figure* 7 shows a summary of impact consumption for the size ranges of glass beads for intensities for which they would be normally used. The figure represents an average of four cycles. Consumption may vary during individual cycles.

Figure 7 *A* shows the impact consumption data we have observed at a 60 degree angle, for some of the intensities and hardnesses in figure 7 are lower. In each case blasting pressure was increased to reach the same arc height with the nozzle 60 degrees to the almen strip surface. A 10 in. distance was used at both angles.

This data should be used as a general indication only. Normally we recommend individual tests of specific applications for more exact data. From the general curves, however, it can be concluded that the harder the surface the higher the consumption of glass beads is likely to be at a given intensity. It is also evident that larger glass beads appear to consume less rapidly than smaller glass beads at the same peening intensity. Generally the actual consumption normally is less than the theoretical 90 degree consumptions given here because blast angles vary on parts of varying geometry and because partially consumed material is included in the active charge, this reduces the flow of active material. Of course, the total economics of any process must be judged by the cost of subsequent operations and the total savings or total value that can be realized by use of glass. In general, the consumption cost of glass should be compared against the cost of passivation or subsequent treatment that might be necessary with other media. Any value that might be ascribed to the more attractive surface which results from glass bead blasting should also be considered.

Of course, sometimes the consideration of fillet radius; requirements for low intensities; for particular surface finishes; to avoid metal removal; or to avoid harm to cutting edges would indicate the use of glass

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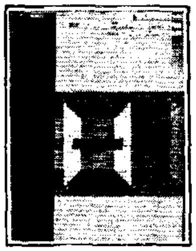

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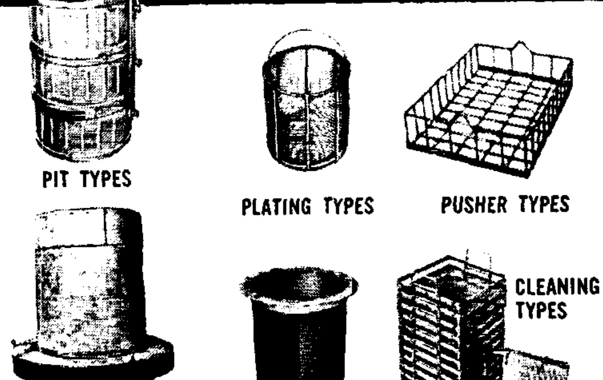

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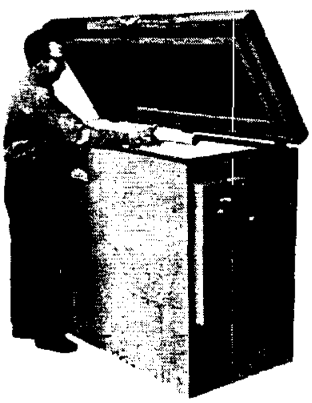

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Figure 7

GENERAL DATA ON CONSUMPTION OF GLASS BEADS IN SHOT PEENING

90° Angle Nozzle

Almen Intensity	Size	Rockwell Hardness	Blast Pressure (direct) P.S.I.	Impact Consumption Average % Per Cycle for Four Cycles
.007 N_2	K(170-230)	54 B	32-37	1.33
		75 B		1.95
		30 C		4.40
		50 C		5.57
	H(100-140)	54 B	20	1.83
		75 B		2.35
		30 C		3.83
		50 C		5.58
.004 A_2	H(100-140)	54 B	45	5.65
		75 B		5.72
		30 C		9.50
		50 C		13.27
.008 A_2	B(30-40)	54 B	12½	1.15
		75 B		1.45
		30 C		2.93
		50 C		8.75
.012 A_2	B(30-40)	54 B	31	3.88
		75 B		4.48
		30 C		7.28
		50 C		13.30

Figure 7A

COMPARISON OF 60° AND 90° BLAST ANGLES FOR IMPACT CONSUMPTION

(nozzle distance in 10")

			90° Angle		60° Angle	
Almen Intensity	Particle Size	Surface Hardness (Rockwell)	Pressure (direct)	Consumption Average % Per Cycle for Four Cycles	Pressure (direct) P. S. I.	Consumption Average % Per Cycle for Four Cycles
007N_2	H(US-100-140)	54 B	20-23	1.83	26-27½	1.13
		75 B		2.35		1.01
		93 B		2.51		2.03
		30 C		3.83		2.51
		50 C		5.58		3.51
004A_2	H(US-100-140)	30 C	45	9.50	72½	5.47

beads as well. In these cases, the consumption data will serve as bench marks for estimating cost of media consumption.

OTHER PROSPECTIVE BENEFITS

Certain private and proprietary tests have indicated that, at least in some circumstances, lower glass bead intensities particularly on aluminum used in aircraft manufacture will often produce greater fatigue resistance. Bock and Justisson[8] have suggested this and we are not without other instances of observation. It is possible that the resulting surface finish produced by glass beads or the effect of developing compressive stress with a low density media may have some beneficial effect. It is well known that smoothness of surface directly increases resistance to cyclic fatigue.

In order to investigate the surface finish to intensity relationship we have gathered isolated tests made at different times to determine the surface finish results that should be expected on surfaces on a particular hardness at a particular peening intensity with particular sizes of glass beads. The results for one surface are in *Figure 8*. Unfortunately, the data is isolated and the creation of generalized RMS information remains to be done.

The possible superior effectiveness of glass beads in establishing greater fatigue resistance remains to be studied in greater detail. There is, however, sufficient evidence available that merits the testing of glass beads in applications using intensities of less than .012A to determine what economic advantage might be gained.

Glass bead peening may also be used as a means of passivation of aluminum. Our tests have shown that treatment with glass beads will leave no residual ferrous material on an aluminum surface after normal blasting. This was accomplished by subjecting blasted surfaces (with glass beads) to salt spray testing to determine if corrosion spots would appear.[9] This further supports the proposition that they can be used as a basic peening media without need of passivation for removal of contamination.

OVERBLASTING WITH GLASS BEADS

In line with the consideration of surface treatment, we have also obtained information regarding the possible advantages of the reduction of surface of steel shot peened aluminum where intensities needed or other considerations require the use of steel shot.

Figure 8

TESTS OF SURFACE FINISH (RMS) AT PEENING INTENSITIES ON 2024 T-3 ALUMINUM

(Hardness: Rockwell B 76 from original surface)

BEAD SIZE	INTENSITY	RMS
B	.010-.012 A_2	160 +
B	.008-.010 A_2	100 — 125
D	.005-.006 A_2	130 — 150
C	.004-.006 A_2	100 — 130

Barton[10] reported the benefits of overblasting peened titanium surfaces from the point of view of increasing fatigue life. Also, when peened surfaces will not meet RMS requirements for aerospace standards often overpeening will accomplish it.

Figures 9 A, B, and C show our isolated tests of specific circumstances for the reduction of RMS or micro-inch of shot peened surfaces. In this data it is interesting to note that similar surfaces may be obtained even with the different sizes of beads by varying the velocity of air pressure to retain the same overpeening intensity. Under certain conditions you can simplify two-step operations and do them in one machine with the same size of media.

Further, overblasting peen-formed surfaces improves surface appearance and develops resistance to stress corrosion. This is practiced by the United States Navy.[11] Peening of surfaces generally with glass beads will inhibit stress corrosion.[12]

PROCESS MANAGEMENT

In dealing with the questions of peening intensity or the development of specific surface finishes maintaining reasonable sphericity in the glass bead active charge in a blasting machine is perhaps the key consideration.[13]

It is necessary, as impact consumption occurs to remove broken particles with a minimum amount of spherical particles coming with them. A maximum count of 15 per cent broken particles is all that is allowed by most specifications in peening operations. The effect of the broken particle is to change the surface finish, especially on non-ferrous metals.

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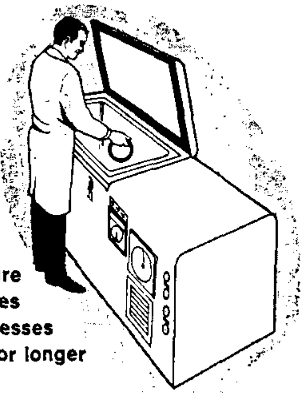

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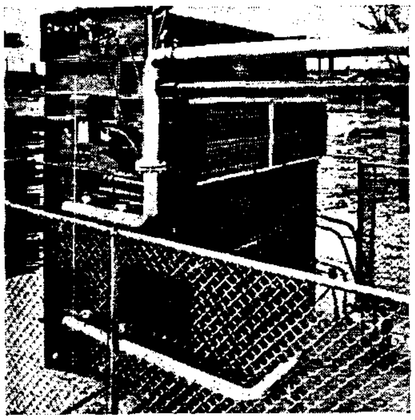

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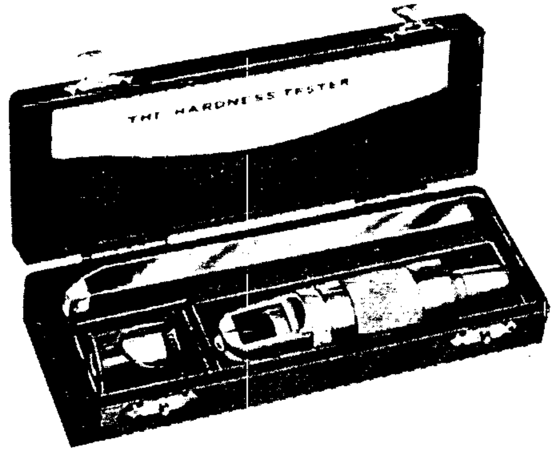

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active charge, the percentage of particles of sufficien mann to produce an appropriate peening intensity wil reduce. It may, of course, endanger the fatigue char acteristics of a part being peened.

Figure 9 (A) RMS

TEST OF REDUCING RMS OF PEENED FINISH OF 7075 T-6-51 ALUMINUM

RMS ORIGINAL	BEAD SIZE	P.S. I.	RMS AFTER PROCESSING
100-110	D	5	60-71
100-110	D	10	66-71
100-110	C	7.5	66-71
100-110	AH	15	80-88
77-82	D	5	72-77

(size AH is U.S. Sieve 170-325 or 44-77 microns in diameter) Tests were performed on a direct pressure machine using a 3/1 nozzle and a 5/32" grit stem.

Figure 9 (B)

TESTS OF REDUCING RMS OF PEENED SURFACES— 2024 T-3 51 Hardness: 74-76 B

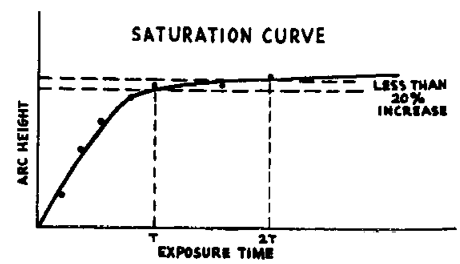
ORIG RMS	BEAD SIZE	P.S.I.	NOZZLE DISTANCE	NOZZLE ANGLE	RM
120-160	D	4	6 in.	60°	90-1
120-160	D	10	6 in.	60°	80-1
120-160	C	15	6 in.	90°	80-9
100-112	C	7½	10 in.	90°	60-7
80-100	D	4	6 in.	90°	55-6
50-60	C	5	10 in.	90°	50-6

Figure 9C

TESTS OF REDUCING SURFACE FINISH OF 2024 T -3 51 (Rockwell B 76) BY PEENING INTENSITY

ORIGINAL RMS	BEAD SIZE	ALMEN INTENSITY	FINAL R
160+	D	.007-.008 N	60-80
160+	D	.010-.012 N	90-120
100-120	D	.007-.008 N	60-80
130-150	D	.007-.008 N	60-80
100-130	C	.006-.008 N	60-80
100-125	AG	.005-.006 N	60-80
100-125	AF	.004-.006 N	60-80
100-125	B	.006-.008 N	60-80
100-125	E	.005-.007 N	60-80
100-125	C	.006-.007 N	60-80
100-125	D	.007-.008 N	60-80

Regular time-to-intensity curves (illustrated in *Figu 10*) for glass bead peening are used to determine th time needed for exposure to achieve specified peenin



results. As in any peening operations it's probably de sirable to seek a time-to-intensity curve for the pa ticular saturation intensity that is required on eac machine used in a specific process. Moore[14] has r ported that the narrower ranges of glass bead m terial produces more satisfactory time-to-intens curves and points toward the desirability of narr size ranging not only for careful control of peening tensities but also possibly for the reduction of proc time and labor cost.

For peening intensity control *Figure 11* shows

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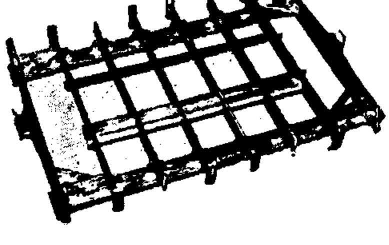

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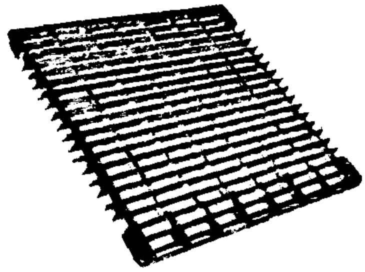

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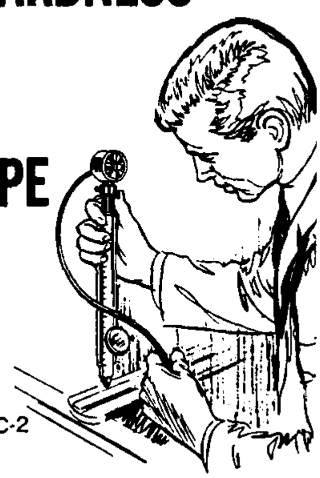

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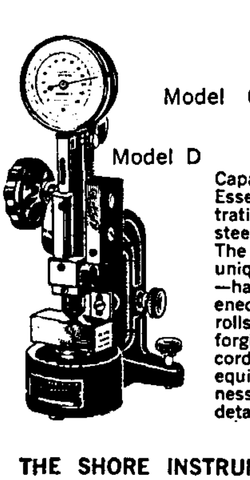

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variations in mass of particles between standard narrow and broad range materials based on U. S. Sieve sizes. It's obvious that material within the broad specification may lean much more easily to the large or to the small. If this were the case substantial changes in peening operations might be experienced.

Upon receipt of glass bead peening media, it is desirable to check particle size and sphericity against material specifications. We've experienced instances of variations in intensity results due to poor screening, to excessive angular particles and to excessive air in the particles.

SUMMARY

The use of glass beads as a shot peening media is developing considerable precedent. Beads are indicated as a peening media where low intensities are required or for penetration of small fillet areas. Further, on non-ferrous or exotic alloy surfaces they can produce economies by avoiding passivation. Evidence exists to indicate that glass beads should be tested to determine if superior fatigue characteristics may result in applications involving intensities of .012A or less. Overblasting with glass beads can be used to perform surface reduction and to prevent stress corrosion. The incidence of successful applications is increasing rapidly.

Figure 11

COMPARISON OF MASS RELATIONSHIPS OF NARROW NOMINAL SIZE RANGE GLASS BEADS WITH BROAD RANGES

U.S.SIEVE	DIAMETER INCHES	DIAMETER MICRONS	RANGE OF MASSES (micrograms)
20-30	.0331-.0234	841-595	272-765
25-45	.0278-.0139	707-357	57-459
30-40	.0234-.0165	.595-.420	96-272
30-50	.0234-.0117	595-297	33-272
50-70	.0117-.0083	297-210	12-33
40-70	.0165-.0083	420-210	12-96
100-140	.0059-.0041	149-105	1.5-4.2
120-170	.0049-.0035	125-88	.89-2.5
140-200	.0041-.0029	105-74	.53-1.5
100-170	.0059-.0035	149-88	.89-4.2
100-200	.00059-.00029	149-74	.53-4.2
170-230	.00035-.00025	88-63	.32-.89
120-230	.0049-.0025	125-63	.32-2.5
170-325	.00035-.00017	88-44	.89

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