A study was made to determine the surface texture in terms of RMS micro-inches resulting from the glass bead peening of five metals. The metals were peened under various conditions of bead size, direct air pressure and angle of impingement. Nozzle diameter (7/32") and distance (6.0") were held constant. Arc Height peening intensity determinations were made for each set of conditions and used to attain uniform (saturation) surface peening of specimens.
INTRODUCTION

Glass beads were first used in the early 1900's mostly for decorative purposes. By the 1930's, they had found numerous applications related to their optical properties. The use of glass beads as an industrial processing media is fairly recent. Starting with a few applications in the early 1950's, glass beads are now used industrially in an extensive variety of processes.

However, most of the industrial applications of glass beads as a materials processing media, fall into three general categories:

1. Improvement of mechanical properties and stress corrosion resistance.
2. Cleaning and deburring.
3. Enhancement of surface texture* for optical or cosmetic purposes.

Due to the transfer of energy from the bead to the target material, peening with glass beads for any of the aforementioned purposes will impart a certain texture on the target surface. This surface texture or finish will be characteristic of the particular combination of the peening factors involved. The factors are: material, bead size and hardness, blast pressure, angle of impingement and nozzle size and distance.

On the same material, if all other process conditions are the same, a given set of glass bead peening factors will produce a specific surface texture. This is so whether the primary purpose of the glass bead blasting is to produce a specific surface texture, or the surface texture is a secondary result of another process objective, say cleaning or peening for enhancement of mechanical properties.

It is apparent then that data correlating material, bead size, blast pressure, angle of impingement, etc., with the resultant texture (in terms of RMS micro-inches) would be a useful addition to present glass bead peening technology. Existent data correlating these factors is somewhat limited and possibly even inconclusive.

Most of the existing data examined does not indicate exposure time or more specifically, the point on the arc height intensity curve to which the material was peened. Logically, it would

* In this study, the words "surface texture" are used as defined by American Standard ASA B-46.1-1969 -2.1 - Surface texture repetitive or random deviations from the nominal surface which form the pattern of the surface. Surface texture includes roughness, waviness, lays and flaws.
seem that peening for a time interval (all other factors equal) that yields less than full coverage (98 to 100%) or more than full coverage* will give different RMS MU in surface texture values.

In consideration of this factor it was decided, prior to the actual specimen peening operations of the study, to establish standards of uniformity. One standard would be established for each set of conditions. Almen test strips were selected as the best means for the preparation of the standards.

The Almen test strip is named after J.O. Almen, formerly of the General Motors Research Laboratory, who developed it, as a method of measuring, specifying and duplicating shot peening intensities. In principle, if a flat piece of metal is clamped to a solid block and blasted with a peening media it will curve, or arc, upon removal from the block. The curvature or arc will be convex on the peened side. The height of the curved metal is measured with a fixed dial gauge and is called an arc height.

The gauge in most general use today is known as an Almen number two gauge. It measures both transverse and longitudinal arcs in one operation. The number one gauge used previously did not compensate for the transverse arc. The number two gauge was used in this study.

There are three types of Almen test strips. They are designated: A, C and N. All three are A.I.S.I. 1070 spring steel heat treated to 44-50 Rc. All three are 3.0" x 0.75". However, the thickness of the strip varies. The N strip is 0.031" ± .001", the A strip 0.051"± .001" and the C strip is 0.094" ± .001" In addition to the thickness tolerance of ± 0.001" the A and N strips have a flatness tolerance of ±0.001" and the C gauge a flatness tolerance of ± 0.0015", prior to use.

The A and N strips were the only two used in this program. Usually the A strip is used in the arc height range of .004 A through .024A. If less then .004A the N strip is used, if it is greater than .024A the C strip is used. The A strip reading is multiplied by three to obtain an approximate N strip reading. Conversely the A strip reading should be divided by three to give an approximate C strip reading.

Arc height and arc height peening intensity designations include the gauge reading, the type of test strip and formerly the gauge number. However, the use of the number two gauge has in general superseded the older number one gauge to such a degree that a gauge number designation is no longer mandatory.

* SAE Recommended Practice - SAE J443. "Coverage approaches 100% as a limit and since actual measurement can be made up to and including 98%, 98% is arbitrarily chosen to represent full coverage. Beyond this value, the coverage is expressed as a multiple of the exposure time required to produce 98%. For example, 1.5 coverage represents a condition in which the specimen has been exposed to a blast 1.5 times the exposure required to obtain 98% coverage."
For example, an arc height designation of say .003A, or as it was previously written .003A₂, means an arc height of .003" using an A strip on an Almen number two gauge.

The Almen test strip is fastened to a holding block or fixture and exposed to a blast of peening media under a set of conditions simulating the actual peening operations on a part. In some instances the part configuration will require that more than one test strip be used. Once a test strip is used it should never be reused.

Before any series of arc heights are determined, correct operational procedure calls for the zeroing in of the Almen gauge. To do it a precision ground flat steel strip 0.156" x 3.0" x 0.75" is inserted in the proper position on the gauge and the dial is set to zero. All Almen strips must be within the stated tolerances. For an exact arc height, all test strips used must be perfectly flat when checked on the zeroed in gauge prior to use.

When a series of like Almen strips are peened under the same set of conditions, at increasing exposure times and the resultant curvatures or arc heights are plotted on a linear graph paper, a saturation curve is obtained. The time to produce saturation may be defined as the time required to arrive at a specific arc height which, when doubling the time of exposure, will not increase the arc height by a definite percentage. For commercial work this percentage is usually twenty (20).

The specific arc height is that point to the right of the so-called knee on the saturation curve. At the Potters Impact Laboratory the percentage limiting the increase in arc height for a doubling of the time of exposure is set at 10%. An arc height may not be termed an arc height peening intensity unless saturation is achieved.

It was felt that, for each set of conditions, the time to attain 100% surface coverage (saturation) would be first determined by means of Almen test strips. Then by the use of a time-area factor (2.55 in this case) the test specimen saturation time, or 100% surface coverage could be determined. It is understood that the time required to saturate an Almen test strip is not necessarily equal to the time required to saturate a specimen of a different material, in terms of cold work. However, in this study we are concerned with cold work only to the degree that it affords a means or tool to determine when all (100%) of the surface has been impacted by beads.

The use then, of the arc height peening intensity curves is the determination of specimen peening times to obtain no more or less than 100% coverage of the specimen surface. If the time required to saturate the Almen strip gauge is multiplied by 2.55 (the ratio of Almen strip to specimen areas) then it should equal the time required to obtain a 100% coverage on the test specimen.
Five materials were tested in this program. They were: A.I.S.I.
1018 steel; AA 2024-T351 and AA 7075-T6 aluminum alloy; A.I.S.I.
type 316 stainless steel and C.D.A. 510 phosphor bronze. These alloys
were selected on the basis of their universality with respect to the
wide range of metals currently processed by glass bead peening techniques.

Prepared specimens of the five materials were glass bead peened
for specific times with eight different sizes of Ballotini beads.
The Ballotini bead sizes were B, D, H, AB, AD, AF, AG, and AH. The
specimens were peened through impingement angles of 90°, 60° and
45°, at air pressures of 10, 30, 50 and 60 PSI. The nozzle to
specimen distance for all tests was constant at 6.0", and the nozzle
diameter constant at 7/32".

Thus the RMS MU in. texture data for each of the five metals treated
in this study is the result of 96 possible combinations of three variables.
The variables (for each material) are bead size, air blast pressure and
angle of impingement.
MATERIALS, FABRICATION OF SPECIMENS and TEST EQUIPMENT

Nominal chemical compositions of the five metals used in this program are tabulated in Table I. Samples of the five materials were checked on a Rockwell Hardness Tester. A tabulation of hardness is also given in Table I. All five metals were purchased as commercial grades. The two aluminum alloys AA 2024 and AA 7075 were purchased in the T-351 and T-6 conditions respectively. The A.I.S.I. 1018 steel, the A.I.S.I. type 316 stainless steel and the C.D.A. 510 phosphor bronze were purchased as cold rolled grades.

The hardness values for all five metals were uniform to within ±1.5 Rockwell B points of the stated averages. All RMS. MU in. texture data for a specific material is at the stated average hardness level.

Two hundred and forty (240) specimens of the five program metals (48 each metal) were prepared. Each specimen was sheared to size (2.0" x 6.0") and assigned two four-digit code numbers, one at each end. The code numbers designated material, bead size, blast pressure and impingement angle. Specimen details are indicated in figure I. Each specimen with appropriate masking was used for two tests.

Techniques similar to those used in metallographic sample preparation were used to polish the test face of each specimen. By applications of progressively finer silicon carbide grits (240 through 600) the specimen faces were polished to a 4-7 RMS MU in. finish prior to testing.

The translation of the time-area ratio from the arc height peening intensity curve to test specimen was deemed a critical factor in this series of tests. Accordingly, a fixture was designed and fabricated to hold and guide the test specimens. The fixture was designed to maintain the face of the test specimen at a fixed distance, in a plane within the confines of the nozzle blast cone, at all times. However, the specimen could be moved continuously to obtain uniform bead impingement over the entire test specimen face. Details of this fixture are shown in figures two (2) and three (3).

A sieve analysis of each of the eight (8) Ballotini bead sizes used in the program was made. A fifty (50) pound bag of each bead size was split 16:1 and then split again 1:1 to obtain two samples, 25 grams each. Figures five (5) and six (6) are the sieve analyses of the eight nominal bead sizes. Each sieve analysis is the average of two determinations. All Ballotini glass beads used in this program were manufactured in the Carlstadt, N. J. plant.

All peening was done with the Model 200P Dry Honer, manufactured by Vacu-Blast Inc. of Belmont, California. This is a direct pressure
unit. The grit stem diameters used are as stated in data relevant to each set of conditions. The test set-up - i.e. area covered by the blast stream from the nozzle, angle, pattern, fixture location, etc. was checked and adjusted with dummy specimens for each set of factors. Templates were used to adjust and check the blast nozzle angle and distance. See figure four (4) for details.
# NOMINAL CHEMICAL COMPOSITION and HARDNESS of PROGRAM METALS

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**TABLE I**
One of the primary program objectives was the establishment of peening standards (time-area) by determination of the arc height peening intensities for each set of conditions. This was done just prior to the actual peening tests. An Almen A or N strip and holder block was set up under conditions corresponding to the specimen peening conditions.

The arc height peening intensity tests were conducted as per the S.A.E. Recommended Practice-Procedures for using standard shot peening test strips. A saturation curve was plotted for each set of conditions. The arc height peening intensity was then determined from the saturation curve by the method previously explained in the introduction.

A tabular summary of the arc height times, determined arc height intensities, and graphs of the saturation curves are presented in figures seven (7) through twenty-two (22). After the arc height peening intensity for a specific set of conditions was determined, the time required to attain it was also determined from the same curve.

The time required to attain saturation of the Almen test strip was multiplied by the factor 2.55. This factor is the ratio of the specimen and test strip areas:

\[
\frac{5.75 \text{ square inches specimen area}}{2.25 \text{ square inches test strip area}} = 2.55
\]

If, for instance, the time required to obtain saturation (on the Almen test strip) was eighteen (18) seconds, this time was multiplied by the 2.55 factor (2.55 \times 18 \text{ seconds} = 46 \text{ seconds}). The peening time for each specimen for that particular set of conditions was then forty-six (46) seconds. A stop watch with increments down to 0.1 second was used to time all tests. A total of ninety-six (96) saturation curves were made, twelve for each of the eight nominal bead sizes used in the program. Each bead size was tested at four (4) pressures and three (3) angles (3 \times 4 = 12).
GLASS BEAD PEENING of SPECIMENS

Subsequent to the actual peening, for a specific time, each specimen was fixtured in the holding guide jig (see figures two (2) and three (3)). Since each specimen was used for two tests, the half not under test was tape masked to shield it from incidental exposure. Specimens were peened, one at a time, in groups of five.

The blast pressure for any given set of conditions was adjusted prior to testing. Nozzle blast activation (foot switch) took place before the test specimen was placed within the bead blast cone area. When the machine air pressure gauge indicated that full nominal air pressure had been attained, the fixtured specimen was quickly positioned in the guide base plate. At this point the test and stop watch timing commenced. The specimen was then moved continuously through an X-Y pattern within the rectilinear confines of the guide base plate. The specimen was then peened for the specific determined time.

At the timed completion of the test the specimen was removed from the confines of the glass bead blast stream. Air pressure was then cut off. This was done because it was found that exposure in a blast of decreasing air pressure (say, 30 PSI to 0 PSI) had an adverse effect on the surface texture.

Glass beads used for any particular set of conditions were checked microscopically at intervals to insure that no more than 15% of the beads were broken. In general, at the lower peening pressures of ten (10) and thirty (30) PSI twelve (12) pounds of beads could be used to peen ten (10) specimens. At the higher pressures of fifty (50) and sixty (60) PSI twelve (12) pounds of beads were used to peen only one set of five (5) specimens. This was due to the faster bead breakdown. At the conclusion of a series of tests each one of the five specimens was air blast cleaned and wiped with M.E.K. solvent.
MEASUREMENT of SURFACE TEXTURE

A specimen holding fixture was made and used to give uniform positioning for profilometer traverses. The fixture also allowed uniform indexing of the specimen for the five traverses. See figure four (4) for details. A Brush Surfindicator (Model BL-110) was used in conjunction with the Brush (Model BL-117A) motor drive stroking unit for all texture measurements. The unit was checked periodically, and if needed, adjusted with a Cali-block. Cali-blocks are precision reference specimens of surface roughness as specified by American Standard B-46.14 and the American Society of Automotive Engineers.

A roughness width cut off (sampling length) of 0.030" was used for all texture measurements. All texture values reported in this study are in terms of RMS (Root-Mean-Square) average in micro-inches at roughness width cut off of 0.030". This term is abbreviated as RMS MU in. for convenience.

Five RMS MU in. texture determinations were made on each specimen (See figure four (4)). The surface texture at any specific sampling site was seldom uniform along the stroking length (1/4") of the traverse. Because of this, and the fact that the profilometer was a direct reading instrument, texture values were recorded as ranges (say, 175 to 195 RMS MU in.). Each range was recorded and reduced to a mean numerical value. The five readings or values from each specimen were then averaged to a single value of RMS MU in. for each specimen. Twenty (20) RMS MU in. values (four pressures, five materials) were recorded for each set of conditions.

A tabulation of the average surface texture in RMS MU in. is given in figures twenty-three (23) through twenty-seven (27). The RMS MU in. values for each material and each set of conditions was plotted versus the relevant arc height peening intensity values, figures seven (7), nine (9), eleven (11), thirteen (13), fifteen (15), seventeen (17), nineteen (19) and twenty-one (21). The resultant graphs are presented in figures twenty-eight (28) through thirty-five (35). Arc height peening intensity curves, figure 9 and figure 13, for the D and AB bead sizes were made with N and A strips. However, in order to unify the data for graphic presentation the A values were converted (multiplied by 3X) to N values.* The converted A to N values were used in plotting the graphs in figures twenty-nine (29) and thirty-one (31).

* SAE Handbook 1972. SAE Recommended Practice. Procedures for Using Standard Shot Peening Test Strip - SAE J443. Figure three (3).
DISCUSSION

The data obtained from this study is summarized in the forty (40) graphs presented in figures twenty-eight (28) through thirty-five (35). The graphs are plotted on the basis of RMS MU in. finish versus arc height peening intensity. Published data relating glass bead peening to surface texture is limited. Most of the data that is available is presented on the basis of surface texture values (RMS MU in.) versus air blast pressure.

However, in regards to surface texture the designation of a specific air pressure which is a process control factor can yield inconsistent results. For the same set of conditions (bead size, impingement angle, nozzle distance etc.) a specific air pressure may produce variations for a number of reasons. The first and probably most important is that surface texture data based on air pressure does not control exposure time. Obviously peening at a time interval that yields less or more than full surface coverage (see footnote page 3) will give a different RMS MU in. value. Even a specific exposure time used in conjunction with a specified air pressure may not yield reproducible textures. For instance, at twenty (20) pounds pressure one machine, depending on its type (direct pressure or suction) may deliver more beads at a higher velocity than another type. In glass bead peening processes, air pressure is a quantitative factor only in so far as the efficiency achieved in the transfer of energy from the beads to the target. In regard to surface texture, a specific air pressure is not an exact precise process factor. This is recognized when glass bead peening is used as a cold working process, and it should be recognized when glass bead peening is used as a surface finishing process.

In glass bead peening, for purposes of cold work, Almen test strips are used as a means of control. Almen test strips can also be used as a means of surface texture control. Saturation of the test strip in terms of cold work can, by means of appropriate area-time ratios, be translated into surface coverage. Consistent attainment of the 98% + coverage will eliminate variations in RMS MU in. values due to under or over coverage.

The tabulation of RMS MU in. values versus air pressure (Figures twenty-three (23) through twenty-seven (27)) indicates little or no pattern of consistency. In some cases what little pattern that is discernible may even be misleading. The same data plotted on the basis of RMS MU in. values versus arc height peening intensity, shows a fairly consistent relationship for each material and set of conditions. There were three anomalies, however, that could not be explained.

Some of the conclusions drawn from this data may also be contradictory to published statements on shot peening. For example, MIL-S-13165 B, 6.8 (d) states "Finish (at equal intensities large shot will produce a finer finish, however, the time required for coverage increases rapidly with shot size)". In regard to the phrase "at equal intensities large shot will produce a finer finish" the data obtained in this study indicates the opposite. In this study, in every case (impingement angle 90°, all other conditions equal), the larger the bead, the coarser the finish.
In some cases, peening at angles of 45° and 60° with small beads at high intensities, produce an apparent anomaly in the RMS MU in. value. On the basis of previous tests, decreasing the nominal bead size (all other conditions equal) virtually always resulted in a finer surface finish. However, at the 45° and 60° impingement angles, this was not always the case. Profilometer measurements made on some materials peened with small beads to a high arc height intensity gave much higher RMS MU in. values than were expected.

Macroscopic examination of the specimens (flat lighting) indicated that in addition to the normal pattern of indentations, the surface was "Wrinkled". It is believed that peening under certain conditions (small bead size, higher arc height intensity) on some materials may produce a lateral displacement of the metal surface. This could produce a compound wave form. The normal pattern of peening indentations would then, be superimposed over a wave pattern of higher amplitude. Since the profilometer measures the compound wave form, the resultant RMS MU in. value would be much higher than might be expected on the basis of simple indentation. Examples of this effect can be seen in the graphs (45° and 60° impingement angles) of AA2024 T-351 and 7075 T-6 aluminum alloy, figures thirty-four (34) and thirty-five (35).

In this study there are references and data tabulations made on the basis of air blast pressure. It should be understood that when air pressure designations are used, they are used only as a convenient grouping factor. Comparisons of RMS MU in. should be made only on the basis of arc height peening intensity, rather than air blast pressure.

The data presented in this study is for five metals of a specific hardness. The two aluminum alloys, AA2024 and AA7075 were purchased and tested in the heat treated T-351 and T-6 conditions respectively. The AISI 1018 steel, AISI 316 stainless steel and the C.D.A. 510 phosphorbronze were purchased as "cold rolled" grades. The lower hardness of the 1018 steel (48 Rockwell B) and the 316 stainless steel (80 Rockwell B) would indicate that one, or both materials may have been annealed subsequent to rolling. The exact time-temperature of the subsequent annealing treatments were not determined.

By definition 8 "hardness is the resistance of metal to plastic deformation usually by indentation". Hence specific RMS MU in. values given in this study would probably be valid only for the same or similar materials at approximately the same hardness level.
CONCLUSIONS

Arc height peening intensities can be used as a tool or means to obtain reproducible surface textures by glass bead peening. The method allows translation of saturation times (for any given set of conditions) from Almen test strips to the specimen or part, by use of appropriate time-area ratios.

Specific surface texture data, plotted on the basis of RMS MU in. finish versus arc height peening intensity is presented.

For the same material peened to 98% + surface coverage:

I. Decreasing nominal bead size -
   a) A 90° Imp. angle always decreases the RMS MU in. value.
   b) A 60° or 45° Imp. angle at lower arc height peening intensities generally decreases the RMS MU in. value. On some material however, peening to higher arc height intensities with small beads may increase RMS MU in. value.

II. Peening to greater arc height peening intensity -
   a) Increases RMS MU in. value for all bead sizes and impingement angles (90°, 60° and 45° tested.)

III. Varying angle of impingement (all other conditions equal) -
   a) A 90° impingement angle always produced lowest RMS MU in. values.
   b) A 60° impingement angle generally produced intermediate RMS MU in. values.
   c) A 45° impingement angle generally produced the highest RMS MU in. values.
REFERENCES

1. A.I.S.I. American Iron and Steel Institute, 150 E. 42nd Street, New York, New York.

2. AA - Aluminum Association, 480 Lexington Avenue, New York, New York 10017.


