AN EVALUATION OF FINE PARTICLE ABRASIVE
BLASTING AND OTHER METHODS OF
SURFACE IMPROVEMENT

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Shot blasting, as a means of cleaning, had been in use for some time before it became generally recognized that beneficial compressive stresses were also imparted. However, there was no control or means of being sure that a consistent job could be done. It was through the work of J. C. Almen and later SAE through Division XX that shot blasting was upgraded to shot peening with controls and recommended practices so that it became an engineering tool. General usage refines that peening is a controlled process while blasting is not. An investigation of the use of a more sensitive test strip indicates that blasting, especially that referred to as fine particle abrasive blasting, can be controlled, and, where engineering properties are involved, the process should be controlled. This also applies to other finishing operations, such as tumbling, wire brushing or polishing, where automatic equipment is used.

The introduction of glass beads as a cleaning or peening material started an evaluation program for possible production use. It soon became apparent that the Almen "A" strip was not sensitive enough to be of much value. This test strip is 3 in. long x 3/4 in. wide x 0.051 in. thick, heat-treated to approximately RC 48 (RC 44-50 specified). In use, the test strip is fastened to a hardened block by four screws and subjected to the blasting medium in a manner similar to that of the work piece. Cold working of the exposed surface tends to elongate that surface, which results in a curvature of the test strip when released from the backing block. The curvature produced is measured by an Almen gage which utilizes a dial indicator to measure the height of an arc 1-1/4 in. in length. Although the arc height may bear some relationship to the cold work effect on the work piece, it should be emphasized that the intended use of the test strip is to control the equipment so that reproducible results can be attained. A strip 0.030 in. thick, later called the "N" strip, with the same length and width as the "A" strip, was chosen on the basis of an approximate magnification ratio of 3-1/2 using the standard Almen gage. This happens to be the same ratio as the "A" strip to the "C" strip, which is used for high-intensity peening beyond the useful range of the "A" strip. It is similar to the "A" strip in all respects except thickness, which is 0.064 in. The "N" strip made from strip stock heat-treated to RC 48, turned out to be quite useful and was instrumental in extending the program to other fine-particle abrasives in production use such as novaculite, grit and sand.

TEST PROCEDURE

In order to get as much as possible out of this program, a test specimen was used such that, by adding a few extra operations, quite a few variables could be evaluated at the same time. The data obtained included effect of air pressure, hardness, and stock removal rates. Surface roughness was obtained, as well as peak stresses and depth of stress produced by the various blasting materials. The specimens used were the same size as the "A" and "N" strips; that is, 3 in. long x 3/4 in. wide, but were 0.200 in. thick. This permitted easy duplication of blasting time, intensity, and area of coverage as on the arc height strips. A working distance of 2-1/2 to 3 in. was maintained between the nozzle and the Almen strips and test specimens.

The specimens were machined and hardened to Rockwell C 25, C 40 or C 60. For stress determinations, one of the 3 x 3/4 in. faces on each specimen was polished to a specular finish sufficient to produce an interference pattern when placed in contact with an optical flat and illuminated by a monochromatic light. The surfaces opposite the polished faces were blasted with various materials at various pressures. Each specimen was again placed in contact with the optical flat to obtain a new interference pattern due to the curvature caused by the blasting. Small increments of stock were removed from the blasted face by etching in 10% nitric with the interference pattern recorded after each increment of stock removal. Biaxial stresses were calculated from the changes in curvature due to the removal of the blasted area. Although measurements were made only in a longitudinal direction, previous experience shows that in the case of peening the curvature is the same in all directions. Consequently, the curvature for the transverse direction was assumed to be the same as that measured. It should be pointed out that the thickness of the specimen was chosen so that curvature produced under blasting conditions contemplated would produce sufficient interference bands for accuracy but not so many as to be difficult to evaluate. Similar specimens, but unpolished, were weighed immediately before and after blasting for 1 min. to measure weight loss or stock removal rates. Surface roughness measurements were also made on these specimens. The blasting time for the stress gradient work was 10 sec., which was determined to be sufficient to produce maximum arc height.

![Fig. 1 - Typical time-intensity curves showing that maximum arc height is obtained in 10 sec](image-url)
RESULTS OF BLASTING WITH VARIOUS MEDIA

Fig. 1 shows typical time-intensity curves for two sizes of glass beads obtained on the "N" strip. Similar curves were run on all of the blasting materials investigated to assure that 10 sec was sufficient time to produce maximum arc height.

Fig. 2 shows the arc heights attainable with various size glass beads using 30, 60 and 90 psi air pressure for 10 sec on both "A" and "N" strips. These data plus additional data on other blasting materials were replotted to show the relationship of the two strips. The conversion factor as indicated in Fig. 3 is close to 3-1/2.

Fig. 4 shows the effect of air pressure on arc height after 10 sec blasting. This chart has been particularly useful in determining the arc height range that can be specified for a given blasting material.

The data on stock removal rates indicate that the amount of breakdown of the blasting material has a pronounced effect. In general, it appears that as breakdown progresses the rate of stock removal increases. Consequently, the data shown in Fig. 5 are strictly for comparative purposes and are intended to show relative effectiveness of the various materials when first introduced into the blasting cabinet. Other factors which have an influence on stock removal rate, such as nozzle size and working distance of nozzle to work piece, were controlled. For the size specimen used, 0.3 g weight loss is equivalent to approximately 0.001 in. thickness.

In Fig. 6 a rather interesting paradox manifests itself in that the stock removal rate using novaculite increases with increased hardness where it decreases with other blasting media as one might expect. Since this trend was consistent in four different tests, there does not seem to be much doubt about it, but there is no ready explanation. It is also evident that, especially at low blasting pressures, glass beads remove practically no stock. Although it is not shown in this figure, the large beads, 0.015 in. diameter, produced about two-thirds the weight loss of the smaller 0.001 in. diameter beads at 90 and 60 psi and approximately the same at 30 psi.

The test specimens used in the weight loss determinations had been ground, having a surface roughness of 16-19 AA. Fig. 7 shows the range of surface roughness obtained on these specimens after blasting. Here again these values are comparative since the original surface roughness could have a decided influence on the end results. As previously stated, the blasting time was 1 min, which is not necessarily a stabilized condition, but probably close enough in this case. However, if a surface roughness of around 100 AA was the initial condition, one could not expect to achieve an AA of 15 with
Fig. 6 - Typical curves showing effect of hardness on stock removal after blasting 1 min at constant pressures. All materials investigated except novaculite showed decreasing rates with increasing hardness.

Fig. 7 - Surface roughness (microin. AA) obtained after blasting for 1 min. Note air pressure has little effect on large beads in 1 min because of the slow rate of stock removal.

Typical stress gradients are illustrated in Fig. 8. The plotted points represent mean biaxial stresses calculated from the changes in curvature with each increment of stock removed by etching. Where the depths of stress were expected to be quite shallow, the increments of layer removal were much smaller. Where reference is made to stress measurements later in this paper, the peak or maximum stress is the maximum compressive stress on the curve, whether it is at the surface or some distance below the surface. Likewise, the depth referred to is that point where the curve crosses the neutral axis and goes into tension. Duplicate determinations on similar specimens usually show a maximum difference of about 5000 psi between the two results.

Fig. 9 shows that the peak stresses are not significantly affected by blasting pressure but that they are more a function of hardness. The values obtained on the Rockwell C 60 specimens are grouped at a very high stress level while the Rockwell C 25 and C 40 specimens are grouped fairly closely together at a much lower level. The values for novaculite 325 mesh appear to be lower than expected but these values may reflect some of the inaccuracies of either the blasting procedures or stress-determining techniques.

Peak stresses are plotted against depth of stress in Fig. 10. Single plotted points indicate values obtained at 90 psi, while the lines represent 60 to 90 psi. Here several observations can be made, some of which were evident on previous figures. As particle size for a given material increases, the depth of stress increases but not the peak stress. It is also true that, for constant particle size, with increase of density or specific gravity of the blasting material, the depth of stress increases with no significant effect on peak stress.

For example, steel grit will produce a greater depth effect.
The depth of stress decreases with increasing hardness of the work piece. The peak stresses obtained at the three hardness levels are plotted against hardness and approximate tensile strength in Fig. 11. The top of the band might be considered the maximum stress attainable if all factors are favorable and the lower limit the minimum peak stress one would expect to find in normal production operations. A quick look at other laboratory data on residual stresses due to peening indicates that all values fall within this band. A re-evaluation of these data result in what might be termed an idealized curve (Fig. 12) which shows the relationship between maximum attainable compressive stress, tensile strength, and hardness. This is assuming no special techniques such as stress peening are used.

Fig. 13 shows a typical "N" strip arc height versus depth of stress plot, for glass beads on Rockwell C 40 specimens. There were insufficient data to attempt a similar plot at any other hardness levels but it is obvious that the slope would be steeper at Rockwell C 60 and less steep at Rockwell C 25. When points obtained from other blasting material were plotted on this graph, there appeared to be a fairly wide divergence from the straight line. There were not enough points for any specific blasting material to justify a different slope or displacement of the line as drawn for beads. It was observed that, although the arc height to depth of stress relationship is a straight line, it does not necessarily go through zero. The "A" strip, being thicker, would have to have a deeper stress present to produce a measurable arc height. This would be more pronounced using the "C" strip. One might conclude that beads give the most consistent and reproducible results.

OTHER FINISHING PROCEDURES

Evaluation of other shop-finishing procedures on Rockwell C 40 specimens is represented in Fig. 14. It is the intention here to show that good finishing procedures will produce compressive stresses, which, under some conditions, might be controlled. The values should be considered typical of procedures used in this investigation but by no means a limitation of what can be obtained by varying the conditions.

Polishing was confined to a 2 in. diameter rag wheel running at 3500 rpm set up with a cold water cement and 90 grit abrasive. Excessive pressure, which is termed "abusive," resulted in lower compressive peak stress but slightly greater depth of stress. Obviously, varying wheel speeds, grit sizes and pressures could produce widely divergent results. Similarly, buffing, which is defined here as noncutting action performed with a rag wheel and abrasive applied with a grease stick, was limited to a 2 1/2 in. wheel with a speed of 5000 rpm and 240 grit abrasive. Here it is observed that excessive pressure changed the stress level from 21,000 psi compression to 15,000 tension and double the depth of stress. This can be attributed to heat generated at the surface causing thermal stress. Both the polishing and buffing were manual operations which were selected by the department foreman when requested to perform these operations.

Tumbling investigation was conducted in a standard production finishing barrel of 48 in. nominal diameter, rotating at 16 rpm. Time-intensity tests were made on Almen "N" strips with Nos. 3-1/2 and 4-1/2 chips and 1 in. x 1 in. blocks. The No. 3-1/2 chip is classified as 5/8 x 1/2 screen size, the No. 4-1/2 as 5/16 x 7/32 screen size and the 1 x 1 block as 1 in. cubic. Maximum coverage or arc height was obtained in approximately 1/2 hr in all three cases. Stress
determinations were made on the interferometer strips as before, after 1 hr exposure to the tumbling medium. There was no apparent correlation between the arc height and the stress gradients, possibly because the arc height values were too small to be significant in spite of the fairly uniform readings obtained on the time-intensity tests, which were continued out to 4 hr. The No. 3-1/2 chip, which was the middle size of the tumbling chips used, gave the highest peak stress of 60,000 psi compression and the greatest depth of 0.002 in. The arc height was only 0.0005 in., while that produced by the 1 in. x 1 in. block was 0.0013 in. The 1 in. x 1 in. block produced the lowest peak stress and the shallowest depth.

The wire brushing and tampico brushing stress evaluation was determined on interferometer strips fastened to the rotary table of a Brushomatic machine, 8-1/2 in. from the center. The table rotated at 7 rpm under a 12 in. diameter brush rotating at 1750 rpm and load readings of 4, 5, and 6 amp. Time-intensity curves had previously been run under the various conditions from 1/2 min to 3 min, which indicated that maximum coverage or arc height was reached in approximately 1 min. A wire brush of 0.010 in. diameter wires with a load reading of 5 amp, and 0.014 in. diameter wires with loads of 4, 5, and 6 amp were the four conditions which were run for 2 min on the interferometer strips. Based on these tests, the smaller wire size gave the higher peak stresses, but the same load (amp) produced the same depth of stress for both wire sizes. A higher load of 6 amp actually produced the lowest peak stresses and did not increase depth of stress. The stock removal rate as compared to a 5 amp load was more than four times as great, and the arc heights on duplicate specimens were widely divergent although good reproducibility had been experienced on the other tests. Obviously this was an abusive condition, especially as far as brush life is concerned. Indications are that wire brushing can be controlled to produce a uniform compressive stress pattern. The conditions which produced the most consistent results might not be the most efficient from a deburring standpoint, but might be an inexpensive way of accomplishing two jobs at once. It does appear that the possibility of doing damage, as demonstrated with the rag buff, is negligible.

SUMMARY AND CONCLUSIONS

In summarizing the various phases of surface finishing or preparation discussed in this paper, several points stand out:
1. Blasting operations which previously have been done as an expedient way of cleaning or finishing can be controlled by taking appropriate steps to produce a uniform peening action.
2. A more sensitive test strip capable of measuring peening efficiency of fine particle abrasive equipment is offered.
3. Compressive stresses produced by blasting —
   (a) increase in magnitude but decrease in depth with increasing hardness, and
   (b) are of the same magnitude for a given hardness irrespective of the blasting material, with only depth of stress being affected by particle size (mass) and air pressure (velocity).
4. Stock removal rates vary greatly with the various blasting materials tested but, in general —
   (a) decrease with increasing hardness,
   (b) increase with decreasing particle size, and
   (c) increase with continued use of a given blasting material, probably because of breakdown producing a finer particle size.
5. Of the other finishing procedures investigated, rag wheel buffing with grease stick abrasive produced the lowest compressive stress and introduced the greatest hazard of producing tensile stresses.
6. Polishing with a rag wheel set up with cold water cement and abrasive showed a wide range of stresses depending upon operator technique, which would put it in the "not recommended" class where a uniform stress pattern is desired.
7. Wire brushing produced the highest compressive stresses and the greatest depth of any of the finishing procedures investigated except blasting, and can be expected to give uniform and reproducible results under controlled conditions.
8. Tumbling offers a consistent method of producing compressive stresses. It appears to be quite flexible due to the wide range of abrasive sizes, the barrel size and rotational speed, and the additive compounds.
9. It appears that the Almen "N" strip can be used to control the consistency of processing by various finishing techniques in the same manner and with the same degree of accuracy as is now being done with the Standard Almen "A" or "C" strip.