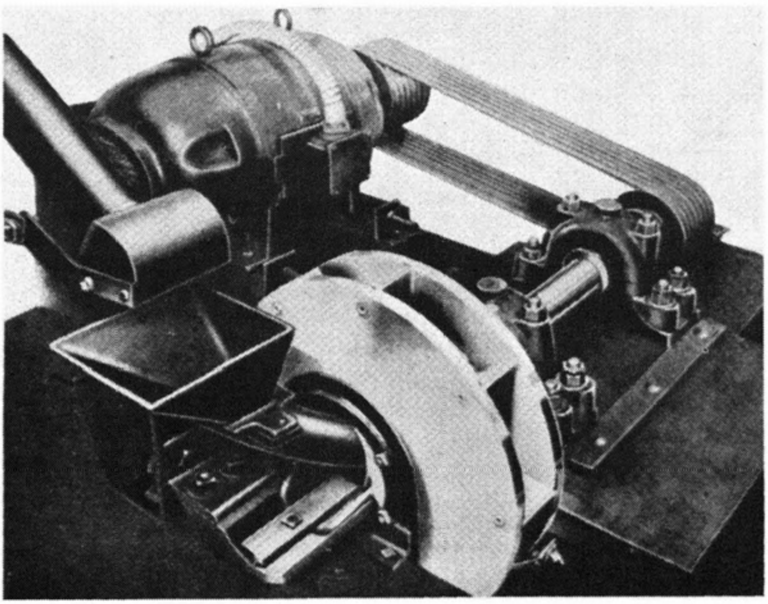

FIG. 1.—AIRLESS WHEELABRATOR UNIT AND DRIVE MECHANISM

PEENING BY SHOT BLAST AND OTHER METHODS

by

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Introduction

Many centuries ago, the artists of Damascus produced swords famed throughout the world by carefully peening their blades and although it is doubtful whether they could have explained the reason behind their art, we know now that it consisted of using just the right blow and right spacing of these blows to cold work the surface of the metal until the optimum conditions as explained below were obtained—the modern phrase is that they produced the correct " coverage."

2. In recent years a lot of work and research has been given to the benefits to be obtained by Shot Peening or Surface Compression by rolling machinery parts, particularly those subjected to fluctuating stresses such as springs, gears, splines, transmission shafts, gun parts, etc. It is proposed in this article to give a brief description of methods, results and applications.

Development of shot peening

3. A very great deal of work has been done on this in the United States of America in which General Motors, Limited, have taken a prominent part. In Great Britain, Vauxhall Motors, English Steel Corporation, J. W. Jackman & Co., Manchester, W. E. Cary, Limited, Toledo Woodhead Springs, Limited, J. Woodhead & Co., Limited, and R. Berry & Co. are some of the firms which use either Air Blast or Wheelabrator Plants. Air Blast Plants are manufactured by J. W. Jackman & Co., Ltd., and Tilghmans Patent Sand Blast Co., Limited, whilst the American Foundry Equipment Company produce the Wheelabrator which is their trade name for a machine described in paragraph 7 and illustrated in Figure 1. Surface compression by rolling has been carried out in Great Britain, United States of America and Germany, but surprisingly little shot peening appears to have been done in the latter country so far as has yet been reported.

4. Shot peening or rolling is now a standard practice for suitable machinery parts with the Ministry of Supply for Tanks and Armoured Fighting vehicles generally. All road springs of all Ministry of Supply vehicles excluding passenger cars are shot peened and a very large amount of research has been carried out by Superintendent of Technical Application of Metals, Ministry of Supply, on these road springs.

5. Shot peening is a cold working method accomplished by pelting the surface of the metal part with round metallic shot, thrown at a relatively high velocity. Each shot acts as a tiny peen hammer making a small pit in the surface of the metal and stretching it radially as it hits. The plastic flow extends .005 in. to .010 in. below the surface and the inner fibres force the outer fibres into a state of compression. Normally changes of dimensions are not important, but an aero engine connecting rod, shot peened all over, may be expected to be .002 in. longer and other dimensions in proportion.

6. It cannot be too strongly emphasised that while considerable production has been attained with shot peening articles, the whole science of the matter is by no means clear, and it would therefore appear to be essential to try out the process on the proposed article very carefully before going into production. In England as far as can be ascertained at present, the size of shot has been practically standardised at 1/32 in. in diameter, the air blast at 30 lbs. working pressure at the nozzle using 1,200 cubic feet of air per minute, a supply of air at

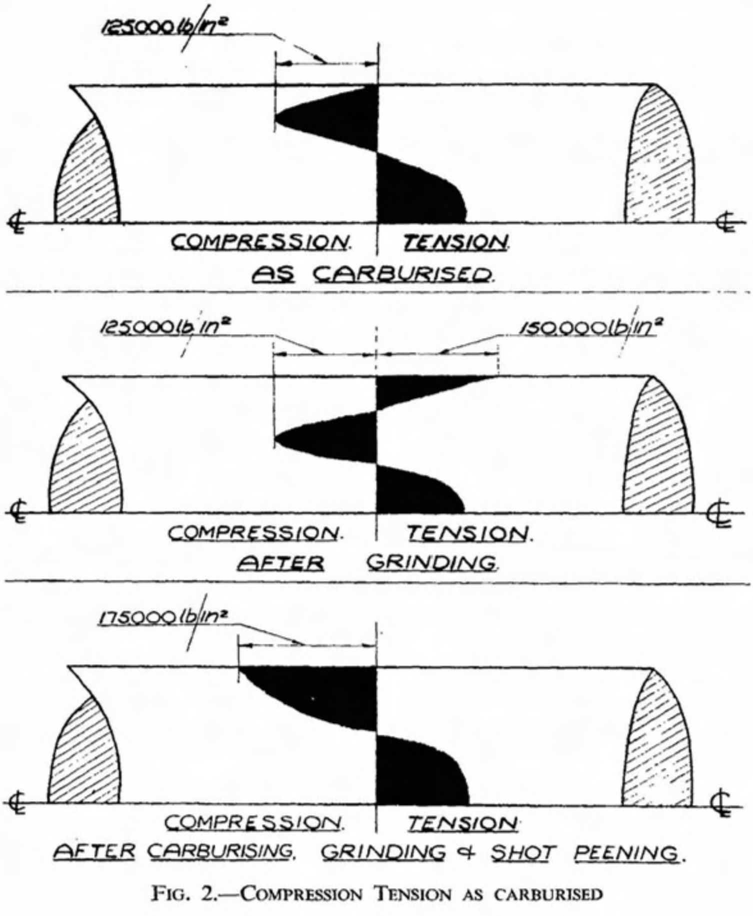

Fig. 2.—Compression Tension as carburised

Fig. 3.—Compression Tension after grinding

Fig. 4.—Compression Tension after grinding, carburising and shot peening

45 lb. per sq. in. and 384 lbs. shot per minute, the rate of treatment being 4 sq. ft. per minute ; the velocity of the shot is most important, as well as the mass ; thus if larger shot are used, a higher air pressure is necessary to accelerate them up to the required speed. Given the shot size, velocity of striking and weight discharged per minute, the rate of treatment is determined to give the correct coverage.

7. The Wheelabrator made by the American Foundry Equipment Co., shown in Figure 1 consists essentially of a bladed wheel driven at high and controllable speed by an electric motor. A hopper feeds the shot to the centre of the wheel and the control of direction of discharge is obtained by varying the point of entry of the shot into the eye of the wheel. The shot are accelerated by the blades to the required velocity and flung at the job. Sizes of wheels range from 1¾ in. wide × 8 in. dia. to 5 in. wide × 19½ in. dia. While this is more economical of power than an air blast system, the air nozzle can be inserted into cylinder bores and similar difficult positions ; also the wear and tear of the nozzle is much cheaper than that of the wheel. In England using 1/32 in. shot, a Wheelabrator speed of 1,800 R.P.M. has been found satisfactory, the work being traversed at 16 feet per minute.

8. Some definite conclusions concerning the process are :—

(*a*) All fatigue failures are due to tension failures and none to compression failures, unless the cross section of the specimen is very weak on the compression side, as for instance the T Bar.

(*b*) Tension fatigue failures commence with surface cracks.

(*c*) Surface cracks, apart from those of chemical origin are due to excessive surface tension. It will be shown now how this excessive surface tension may be ameliorated.

(*d*) While the ultimate strength may be increased slightly, higher stresses should not be included in designs as the object of peening is to attain the possible life without failure due to fatigue and so avoid some of the disappointments found when using modern highly stressed steels.

(*e*) Fatigue life is increased by anything between say 200% and 3,000% for parts which are suitable for the process.

How shot peening works

9. A case hardened steel rod will have internal stresses as shown in Figure 2, where there is no stress of the surface layer, but immediately under the surface layer there is a compression of, say, 125,000 lb./sq. in. balanced by a tension in the core.

10. If this hardened steel rod is now ground, a very great change takes place in the internal stresses as shown in Figure 3. A surface tension of up to 150,000 lbs./sq. in. will have been set up.

11. However, if this hardened and ground steel rod is now subjected to shot peening, and the shot peening is carried out to effect the best results, a further remarkable change takes place. The tension due to the grinding is completely eliminated and a surface compression is set up of 175,000 lbs./sq. in. as shown in Figure 4.

12. It is essential to understand that heat treatment will release all of the internal stresses mentioned above and shown in Figures 2, 3 and 4. The release commences at about 550°F. and increases as the temperature rises, being complete at about 950°F. This means that shot peening is of reduced value for machinery parts which work at temperatures of over 550°F. and quite useless for those working at say 800°F. or higher.

13. Paragraph 10 illustrates the bad effects due to grinding and explains the well known surface cracks sometimes found in ground machinery parts ; while paragraph 11 illustrates how this disability can be overcome and turned to great advantage by peening, it cannot be too highly emphasised that any surface discontinuity will certainly have a most disastrous effect on fatigue life. Some

of such surface discontinuities are absence of fillet, fillet with too small a radius, careless tool marks, ground portion ending abruptly and leaving a ridge and so on. This matter has been very well illustrated by transmission parts in heavy tanks. Since the introduction of peening, no transmission part has failed due to design but many have failed due to lack of faithful workmanship and the utter impossibility of 100 per cent. inspection under wartime conditions. The more highly a part is stressed the more essential it is to have a fillet of suitably large radius ; hence good practice in wrought iron or mild steel may be very bad practice in high tensile steel. How very often high tensile bolts and rivets are found without a fillet with the result that the heads fly off when subjected to shock, sometimes even failing when hardening up. It cannot be too highly stressed that bad design and bad workmanship cannot be made good by shot peening.

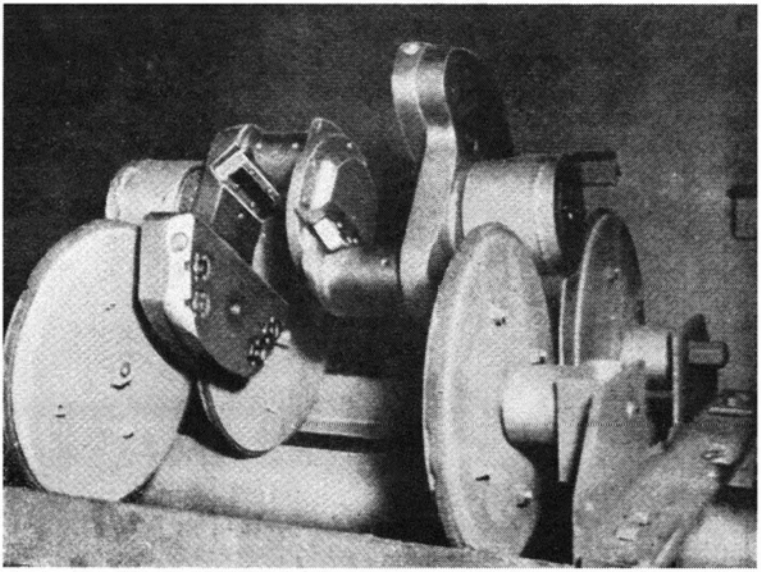

FIG. 5.—USING ALMEN TEST STRIPS TO DETERMINE PEENING INTENSITIES

Shoulders and fillets

14. It is possible in many cases to arrange the shot plant so that shoulders and fillets can be treated and Figure 5 relates to this and shows a crankshaft specially prepared as an exhibition piece. Shoulders on shafts, etc., are frequently similarly " worked " not by shot but by a special roller the face width of which is continuously varying so that the work is " kneaded " ; the job is driven between centres of a lathe and the roller is pressed against the fillet by a spring with a predetermined force and rotates with the job ; the roller axis at 45° to the axis of the job. There is a controlled relationship between the roller profile and diameter, the diameter of the job and the force of application. Experience and trial and error are needed to determine the best arrangement. The roller contact pressure should be such as to give a Hertz stress of about 6,000 lb./sq. in. While shot peening gives equal surface-layer compressive stresses in all directions, surface rolling does not necessarily do so.

15. Shot peening produces a satin finish and this has been found quite beneficial to lubrication in such parts as transmission gears of tanks. In some

other cases it has been found to have a bad effect. This can be got over by lapping or honing a small portion of the peened surface away, taking the most extreme care that the lapping does not go too deep and so remove all the layer which is in compression ; .002 in. should be regarded as the top limit.

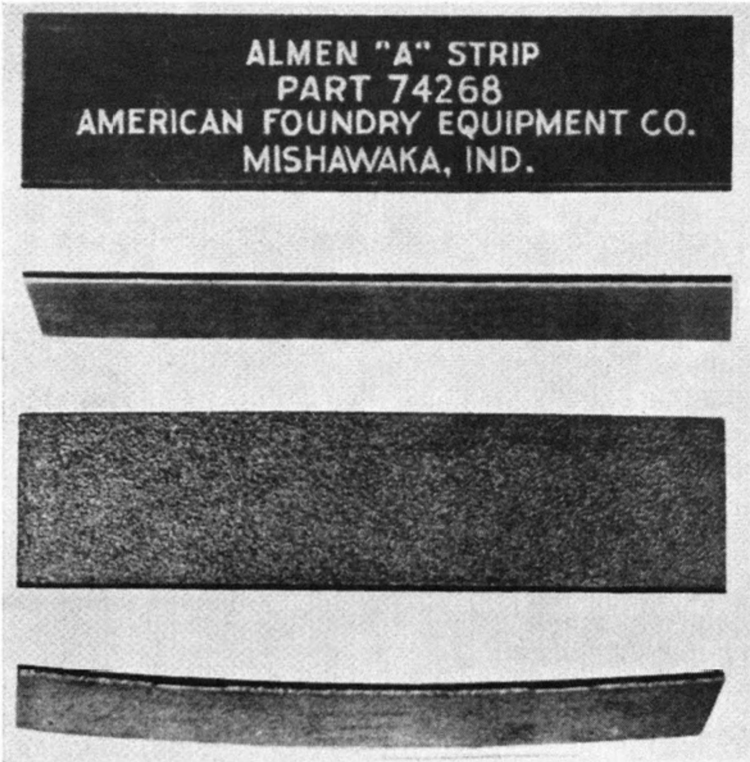

FIG. 6.—ALMEN TEST STRIPS BEFORE AND AFTER SHOT PEENING.

Determination of intensity

16. In the United States of America, many different sizes of shot are used with other factors varied to suit, and great faith is attached to the Almen Gauge. The Almen Gauge is a device for measuring the intensity of shot peening, invented by J. O. Almen of the General Motors Research Laboratories. Figure 6 shows test strips before and after shot peening. It will be noted that after shot peening, the test strip is curved and the arc height of this is measured by a simple gauge as shown in Figure 7. This arc height is a measure of the degree of peening attained under the circumstances of the test.

Two sizes of Almen test strips are used : the A strip for light work on which the arc height will not exceed .016 in. has the following specifications :—

Length	3 in. ± .015 in.
Width	.750 in. to .745 in.
Thickness	.051 in. ± .001 in.
Hardness	Rockwell " C " 44 — 50
Flatness	± .001 in.

For arc heights exceeding .016 in., the " C " test strip is used ; this is the same as the "A" strip except it is .0938 in. ± .001 in. thick. Figure 8 shows the holder for this test strip and Figure 5 shows the test strip fitted in an awkward place on a crank shaft to control the peening of it.

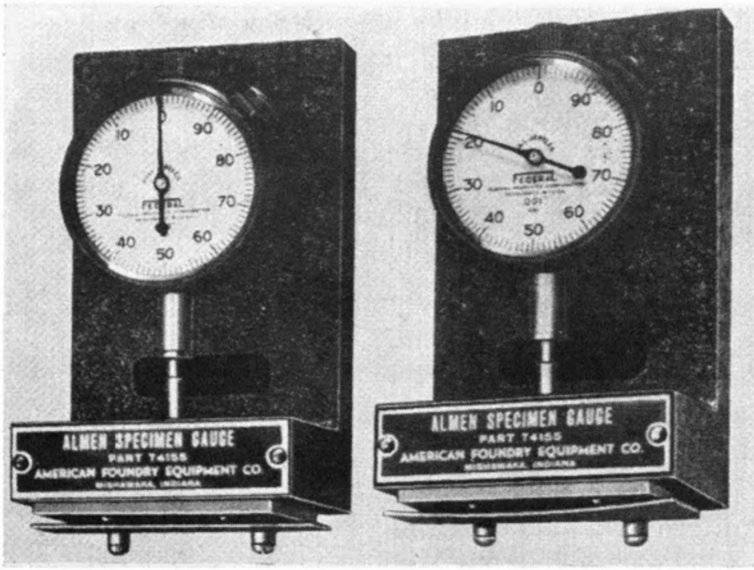

FIG. 7.—ALMEN SPECIMEN GAUGE FOR MEASURING ARC HEIGHT OF ALMEN TEST STRIPS

Application to vehicle springs

17. As stated in paragraph 4 all flat springs for Ministry of Supply lorries and above are shot peened ; this is done on the tension side only, which is normally in the black condition. This leaves variable factors in the surface such as forging marks, scale and decarburised layer and so the results are quite variable. Exhaustive tests have been carried out at Vauxhall Motors in a machine at 350 cycles per minute with stress on the tension side varying between 30,000 and 140,000 lbs./sq. in. The untreated average life with Maker A's springs, are 25,000, while the peened springs have an average life of 215,000 cycles ; the figures for Maker B's springs are 81,000 and 726,000 and for Maker C's springs 76,000 and 444,000. No peened spring ever broke at less than twice the life on the best untreated spring, while some persisted in astronomical lives of 4 million cycles or more.

18. The peening coverage shown by Almen test strips have not shown any direct comparison with the fatigue life of the corresponding springs in these tests.

Shot

19. The shot supply is a very big problem as the quantities used are very large. The shot is manufactured by breaking up a stream of molten iron by a jet of water, steam or air and collecting the shot in water. They are then carefully screened and as stated above shot of about 1/32 in. diam. are generally used in this country. The chilled cast iron has a poor life, the shot break up badly, necessitating elaborate screening to clean out the fragments. It is fully appreciated that shot such as might be made mechanically from steel wire,

would be infinitely preferable but the enormous numbers of individual shot required prevent this from being a commercial possibility at present.

Surfaces with sharp edges and general remarks

20. In shot peening articles with sharp edges the surface layer will be pushed out into a ragged fin unless the corners are protected or chamfered. Protection is easily obtained by rubber tape or pads. Rubber is also used for lining pipes and nozzles. Shot peening does not directly affect the rusting of steel but it delays, and to a certain extent, inhibits the formation of corrosive pits which form starting places for fatigue cracks. Shot peening can be applied to gear teeth without causing any appreciable distortion. Less expensive steels can be utilised when shot peened in lieu of higher grade material.

Application to non-ferrous metals

21. While the foregoing refers to articles of steel the benefits of shot peening or surface rolling are also applicable to cast iron malleable iron, bronze, brass, aluminium, magnesium, nickel copper and zinc articles ; while a lot of work has been carried out, sometimes with considerable success, much remains to be done on all of these and the numberless alloys involved ; there are dangers of iron contamination and consequent stress corrosion cracking with magnesium alloys.

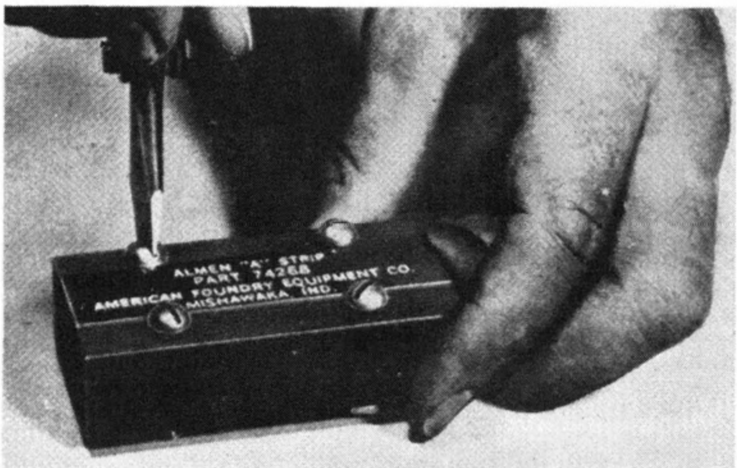

FIG. 8.—THE ALMEN TEST STRIP HOLDER

Special applications

22. All sorts of mechanical devices have been set up to enable various jobs to be efficiently peened, turning and traversing the items as necessary during the operation, *vide* Figure 9, these devices should be rubber covered. In many cases it is preferable to control by hand the job on a suitable rod. Dust cabinets are essential.

23. Studs and bolts with threads rolled and the plain portions shot peened or surfaced rolled are much stronger and more reliable than those manufactured in the ordinary way, one case being reported as having 16 times the life. The rolling of threads is another illustration of surface working and is similar to shot peening and surface rolling. This applies more particularly to fine

threads. The threads can be fully produced by rolling or have only the roots worked by a roller after machine cutting.

24. A famous British aero-engine has four banks of cylinders ; these drive the propeller shaft through double-reduction gears, ratio about 4 : 1 and there are four pinions driving the main wheel, which is roughly 10 in. diameter 1¼ in. wide, teeth .74 in. circular pitch, helical angle 10°. Only one tooth is in contact at any moment and between 500 and 600 H.P. are transmitted through it at 870 R.P.M. of the main wheel. The teeth bend both radially and axially under this load and are carefully shaped to counteract these deflections—this has been done by trial and error as the slightest lack of perfection under load rapidly destroys the gear. Now the gears are regarded as having an indefinitely long life. Before this was attained, however, it was found that they broke by fatigue

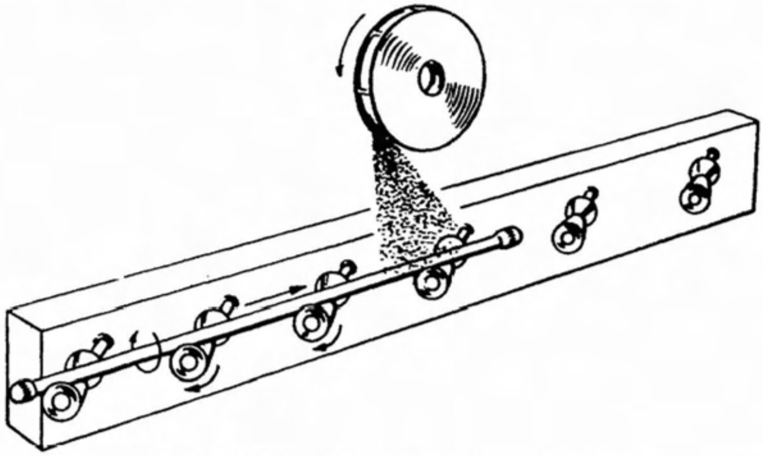

FIG. 9.—METHOD OF TURNING WITH TRAVERSING

cracks at the root. Research into this, *vide* paragraph 10 above, found that grinding was the trouble and this was completely overcome by lapping by hand the root space between each pair of teeth with paste and a soft steel rod spun at high speed by a small electric motor. This cut away the surface layer under tension but it would have been much better to shot peen. However, this episode took place before shot peening had become established. This lapping substituted surface scratches at right angles to those made by grinding ; the latter turned the job into a " notched bar " but the former are quite harmless to strength.

Conclusion

25. It is felt that there are many applications in the Navy for this science of surface working. Highly stressed items such as studs and bolts, gear wheels, internal combustion engine, gun and gunmounting parts which are subjected to fatigue could all be made with much longer lives and hence of much greater reliability. It would be worth considering whether expensive turbine blading failures through fatigue cracks might be avoided ; the question of working temperatures comes into this.