SHOT BLASTING AND ITS EFFECT ON FATIGUE LIFE

BY F. P. ZIMMERLI

Abstract

This article deals with a new method of surface finishing called, for want of a better name, "shot blasting." A fatigue machine for small springs is described. Data from this machine show that by using valve spring wire, increases in fatigue values exceeding forty per cent have been obtained. Results on other materials are presented. The investigation demonstrates that excessive heating will remove the beneficial effects. Various commercial factors, as size of shot, velocity of impact, methods of applying shot to work, etc., are discussed.

YEARS ago Herbert[1] in England called attention to what he described as cloudburst hardening. Since that time the matter fell into abeyance and little work was done along these lines in this country. In 1929 the company with which the author is associated sent out the first production springs in this country shot blasted to increase fatigue limits. These springs were first unnoticed, then protested, and for a year or two our work was endured but not encouraged. After that, adoption was rapid until today this method is specified on many prints.

This surface treatment has been employed for eleven years in our plant and has done more to increase fatigue life of small springs in *particular* than any of the alloy steels ever used. The steel sizes with which we have done most of the laboratory testing have been less than ¼ inch, but much work has been done up to ¾ inch wire diameter.

Shot blasting consists of propelling small steel balls against the outer surface of the object to be treated. This can be accom-

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[1] Work Hardening of Steel by Abrasion, Engineering, Vol. 124, p. 470, 1927.
Cloudburst Process for Hardness Testing and Hardening, TRANSACTIONS, American Society for Steel Treating, Vol. 16, No. 1, p. 77, 1929.
Hardening of Super Hardened Steel by Magnetism, Engineering, Vol. 128, 1929, p. 569.

The author, F. P. Zimmerli, is chief engineer, Barnes-Gibson-Raymond Division of Associated Spring Corp., Detroit. Manuscript received April 30, 1940.

plished in many ways, but in commercial use we find two types of machines that are most adaptable. The older of these methods is by the use of air for the propelling agent as in the common sand blast equipment. The second method is mechanical, the shot being fed on a rapidly rotating wheel having radial blades. The energy is transferred to the shot by the blades and by centrifugal force. The shot is thrown on the work. Tests have shown that either method will produce the same results in increasing fatigue life. However, the mechanical machines will do it much more quickly.

In order to appreciate what shot blasting can do to fatigue life, it is necessary to know the exact fatigue life of material before the process was applied. Similar data on unblasted steels have been previously published in Engineering Research Bulletin No. 26 of the University of Michigan for many materials and the same procedure to obtain the basic values of the various materials was employed here.

Since a large number of springs had to be tested in order to secure enough data as a basis for reliable conclusions, a special testing machine was designed. Every effort was made in designing this apparatus to avoid any effect except the action of simple compression and release of the springs themselves.

The machine had to meet the following requirements.

1. It had to handle a reasonable number of springs simultaneously.
2. It had to be adjusted for varying loading conditions.
3. It had to impose the calculated spring loads accurately at desired speeds with no spring surge.
4. The machine had to note the number of stress applications and, in case a spring broke, to record the fact and when it occurred.
5. For economical operation the machine had to be self-protective so that it could be run for long periods of time without attention.

The mechanism designed to meet these requirements is shown in Fig. 1. It consists of a double-throw crankshaft to which, by means of connecting rods, a walking beam is attached. Upright rods to a header transmit the motion to springs mounted on top of the machine. The whole is driven by a variable speed electric motor.

The machine is wired to a magnetic relay so that the eight springs are connected in series and also in series with an oil pressure regulator so that, should a spring break or the oil pressure to

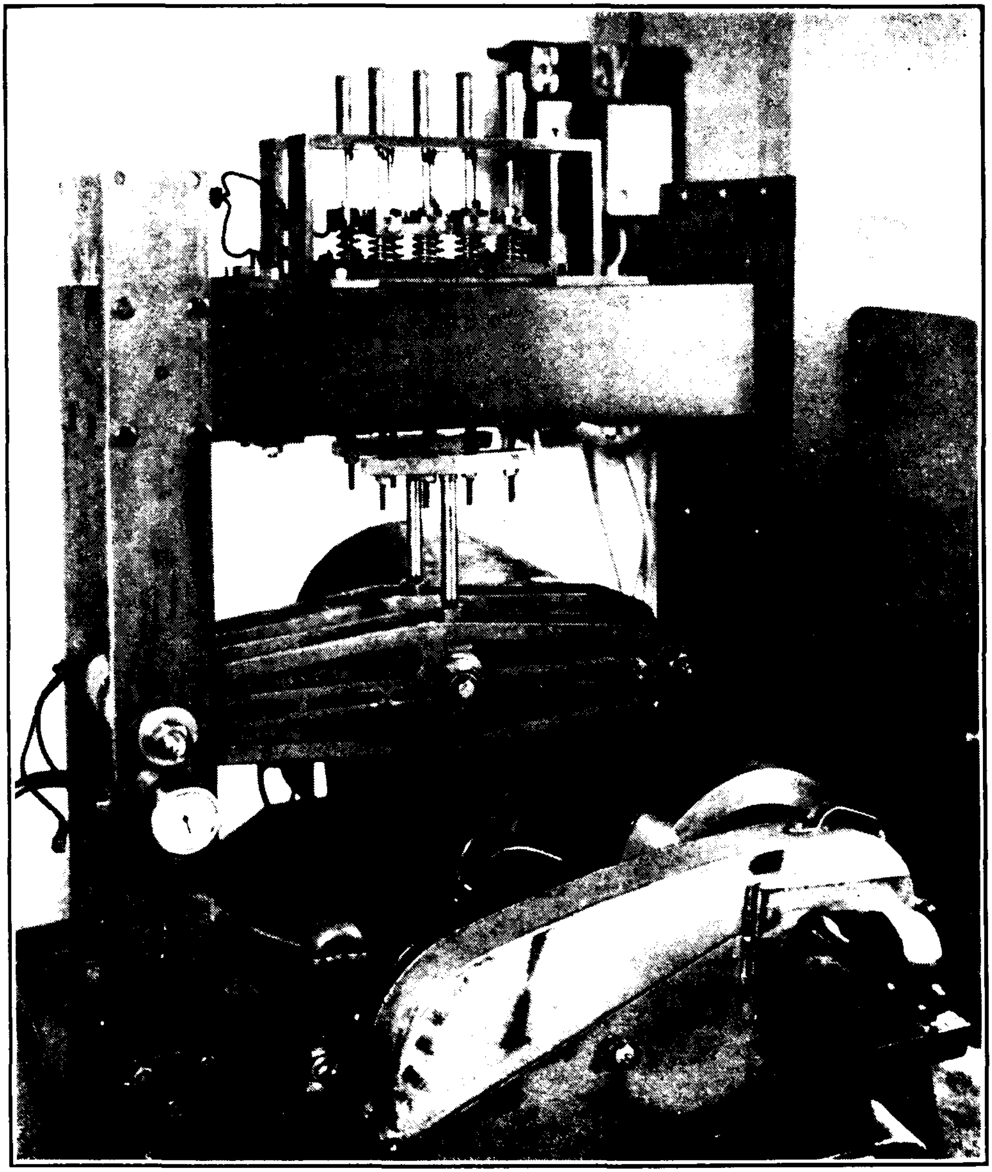

Fig. 1 Fatigue Machine with Standard Spring Test Setup.

the bearings fail, the machine would stop, since the magnetic circuit breaker would throw out and break the drive motor circuit. A counter attached to a 100-to-1 gear reduction automatically counts the number of spring compressions while the machine is running. The motor speed range of 1000 to 3300 revolutions per minute is carefully tested by means of a neon light, or vibroscope apparatus, and at no speed is there any spring vibration or surge. Actual testing speeds varied somewhat with different wire sizes, but averaged 2500 revolutions per minute.

TESTING PROCEDURE

In order to duplicate results and reduce the influence of unknown factors, the following procedure has been adopted as standard. After all laboratory tests, the wire to be used is carefully coiled into springs. The springs are then hand-ground and heat treated, or, if made from pretempered wire, are heated to relieve coiling strains at 750 degrees Fahr. No springs are pressed solid after coiling as it is felt this makes accurate stress calculations impossible on account of trapped stresses in the springs themselves. It is appreciated that this pressing solid increases the physical strength of the material as is usually done in spring manufacture. The springs are then load-tested and tagged until ready for insertion in the machine.

As can be seen, four springs can go into each side of the machine and each four can work through a different range if desired. Each spring is individually adjusted to the first stress desired and the throw adjusted to bring the second stress. Eight springs are used for each run; if one spring breaks, the run is judged to be unsatisfactory. All runs are made on the assumption that if the springs withstood ten million reversals, they have an indefinite fatigue life. All broken springs are carefully examined as to possible cause of failure other than fatigue. If any microscopic or macroscopic evidence is found that the material has failed through some other condition than fatigue induced by excessive stresses, the entire run is discarded and the results are not included.

Because of the carbon content, fine grain size, and sorbitic structure of the steels after tempering, it cannot be proved microscopically by examination as high as 1500 diameters where the fatigue failure started. It is believed that overstressing, which results in fatigue failure, starts inside the individual grains and actually breaks the grain into smaller sections, moving these sections by each other. Actual tests have shown that steel stressed over the fatigue limits given in this work has a rise in temperature which steel stressed slightly lower does not show.

All stress calculations are based on the formula by A. M. Wahl. This gives a summation of torsional and shearing stresses.

$$\text{Maximum stress} = \frac{16\ Pr}{\pi d^3} \frac{(4c - 1)}{(4c - 4)} + \frac{0.615}{c}$$

In this formula—

P = axial load in pounds
r = ½ mean diameter of the spring
d = wire diameter
c = $2r/d$, i.e., ratio of mean diameter to wire diameter

This maximum stress occurs on the inside of the spring.

Sample coils of the various spring wires to be tested are analyzed, and etched, and examined microscopically for dirt or other inclusions. Unless these tests show the steel to be of a good grade, free from scratches, seams, or other imperfections, it is not subjected to test.

Springs are placed in the fatigue machine and runs made with various stress ranges. The stresses are made high enough to insure breakage, and then in subsequent tests reduced by small decrements to the point where fatigue failures do not occur. In this manner it is possible to establish the endurance limit of the steel being tested for a given minimum stress. The maximum error in these fatigue tests is established as plus or minus 3000 pounds per square inch as calculated by the Wahl formula.

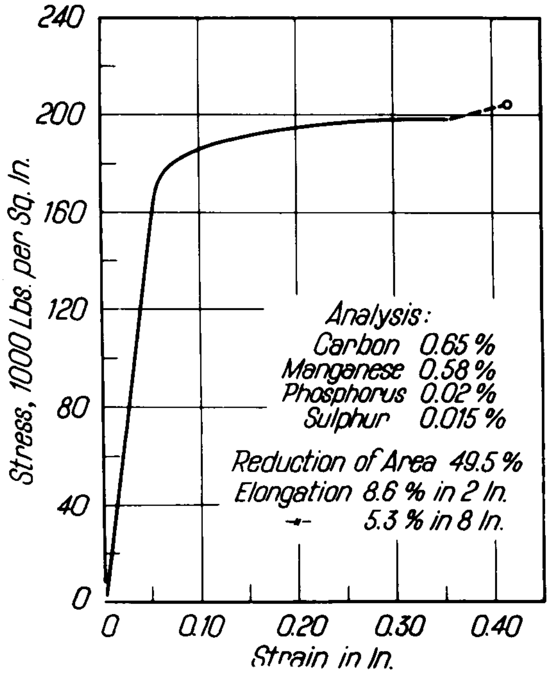

Fig. 2—Valve Spring Wire Stress-Strain Curve.

In this investigation the first runs were made to study the effect of time of exposure to shot blasting with all other conditions held constant. It was appreciated that this factor was of prime importance and would vary somewhat with each type of spring and method of treating. A bundle of valve spring wire was selected, size 0.162 inch, for these tests. The physical properties of this wire and its chemical analysis are shown in Fig. 2. The springs made were $1\frac{7}{32}$ inch O.D., 3¾ active coils, 1⅞ inch free length, ends squared and ground. They were heated to 750 degrees Fahr. after coiling and of course were not pressed. The fatigue range before shot blasting was 20,000 to 95,000 pounds per square inch. The astounding results of the shot blasting are shown in the results presented in Fig. 3. The maximum stress has increased in this test about 42 per cent, a greater increase than any other known treatment even approaches.

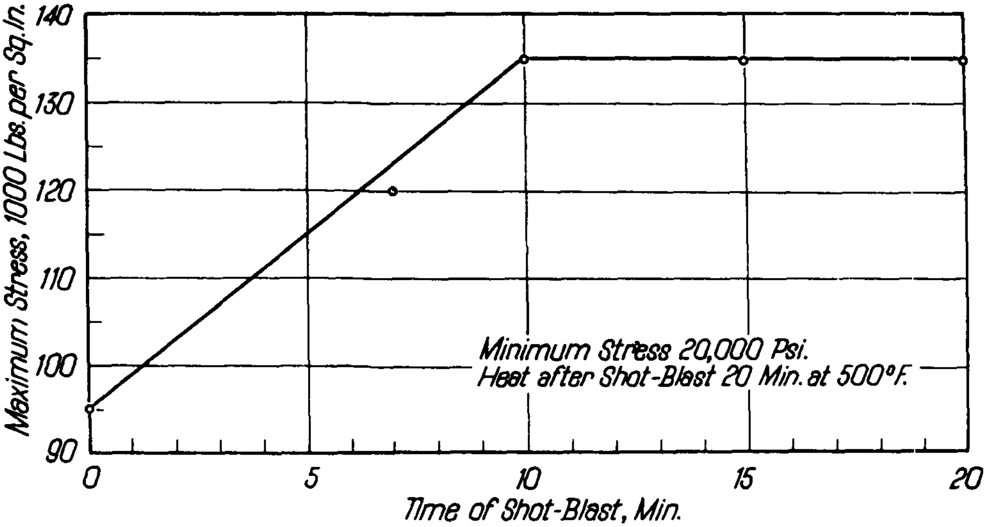

Fig. 3—Effect of Time in Shot Blast on Test Springs.

In the commercial shot blasting of small springs the duration of the treatment is a function of the number. When too many springs are put in any type machine, the mechanical type as employed above or the air type, they will not be properly treated. Exact details depend on the machine and type of work. They can be determined only by experiment. In our tests air blasting equipment took three times as long to produce these same results when using 65 pound air pressure.

With this information at hand the next question to be considered is what causes this increase in life and what affects it? More of the springs were properly blasted and heated afterwards to various temperatures. The fatigue machine then gave the results shown in Fig. 4. At 825 degrees Fahr. we have the same stress range, viz., 20,000 to 95,000 pounds per square inch as before the blasting. In other words, this heating has removed the beneficial effect of the shot blasting which apparently was nothing but cold work of the outer fibers. A reblasting will reproduce the same high fatigue resistance.

Microscopic examination supported the conclusion that the effect is due to cold work.

This influence on the surface of the steel extends, as can be seen, in the photomicrograph Fig. 5, a minute distance inward. The small amount of material greatly augmented in strength and prestressed by the peening action is responsible for the change in fatigue resistance.

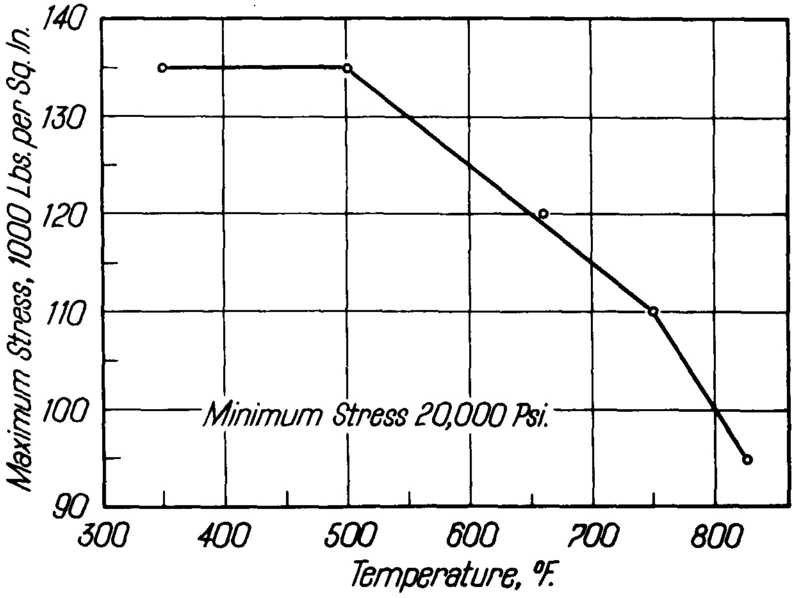

Fig. 4—Effect of Heat on Shot Blasted Springs.

With these thoughts in mind it became necessary to investigate the effect of the size of shot. On the size springs usually subjected to the treatment in our plant, large balls are impossible to use since they cause the parts to be hammered out of shape. We did, however, obtain shot $\frac{1}{64}$ of an inch in diameter and $\frac{3}{64}$ inch in diameter. Since this corresponds to a volume increase of approximately 27 times with the consequent weight per unit particle in direct proportion, a noticeable variation in fatigue results was anticipated.

Tests which were run on more springs from the same type of wire gave the same fatigue limit with either shot size. There was, however, one difference and this was in favor of smaller shot to a slight extent. On this run those springs which were set high enough in stress range to break ran longer when blasted with the small shot. A light sand blast for three minutes still further increased the length of run but the springs would not go ten million cycles at any higher stress than that obtained with the coarser shot. This was on a 0.148-inch wire. On $\frac{3}{16}$ inch wire the reverse results were obtained

Fig. 5—Showing Cold Work and Rough Surface Due to Shot Blast. × 100.

in that the heavier shot appeared slightly better. Pictures illustrating the types of surface obtained with coarse and fine shot are shown in Figs. 6 and 7.

These photographs also illustrate the fact that a rough surface is not a sure cause for failure. Here we see that even with these pitted surfaces a greater fatigue life is obtained than with the normal smooth surface. This is undoubtedly in spite of and not because of the roughness.

Material in a straight section was carefully polished with jewelers' rouge of the same grade as used to prepare metallographic samples. This was tested in a machine as outlined in our work on "The Effects of Longitudinal Scratches on Valve Spring Wire," published in TRANSACTIONS of the American Society for Metals, Vol. 26, 1938, p. 997. We received a torsional fatigue life less by far than the blasted springs give. Further testing with metallurgically sound pretempered valve spring wire indicates that wire can be produced and blasted so that the resulting compression spring is self-protecting. This is done by proper heating after coiling so that the spring if

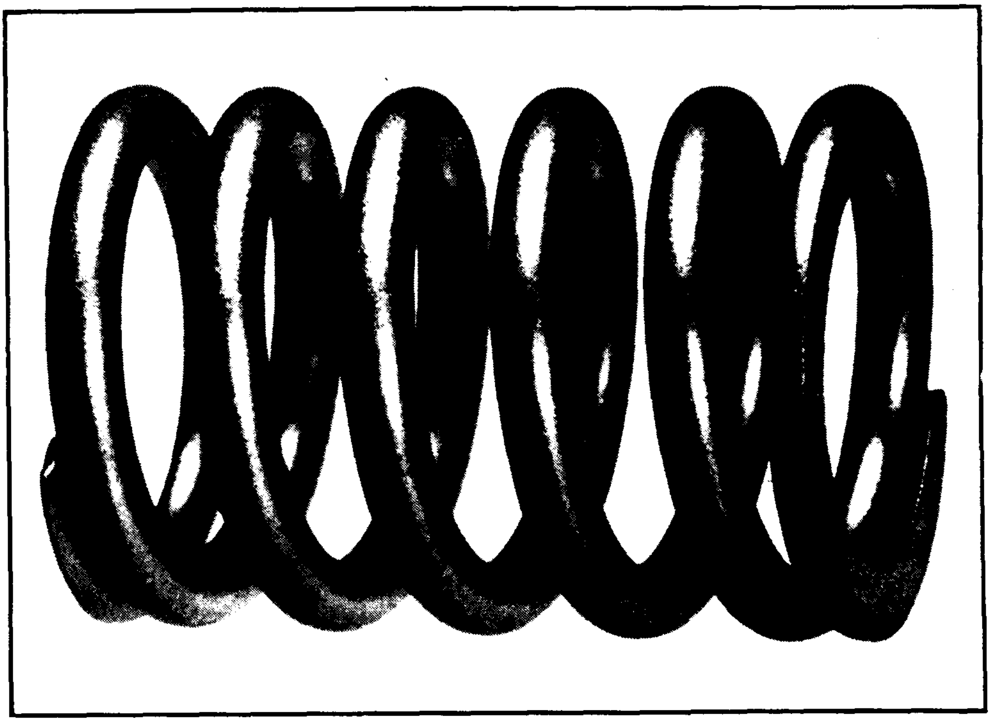

Fig. 6—Surface Produced in Using Fine Shot.

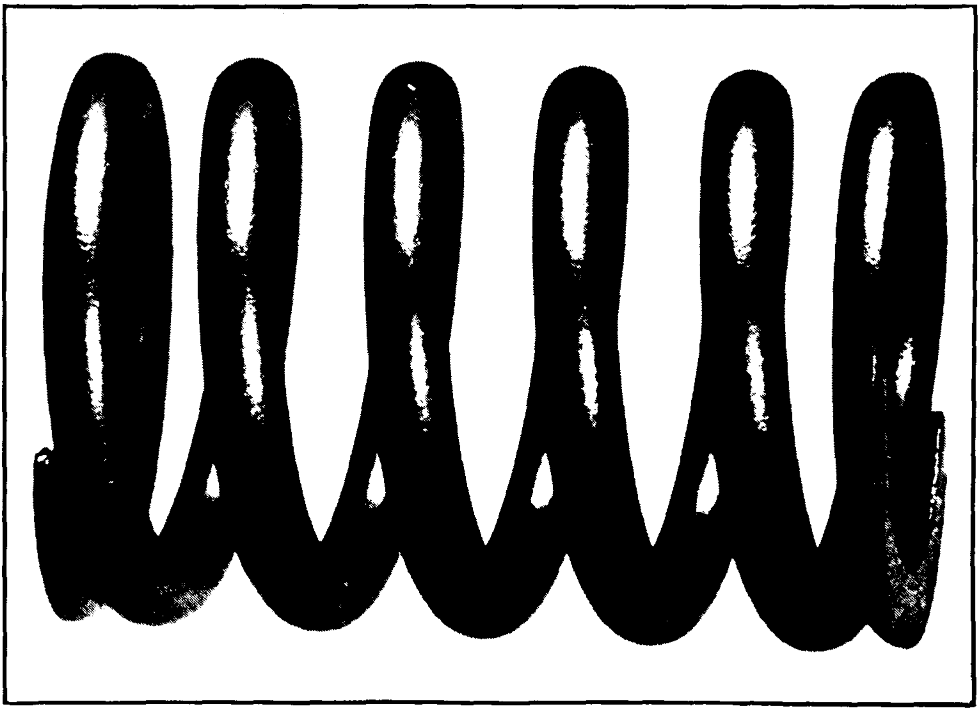

Fig. 7—Surface Produced in Using Coarse Shot.

overloaded will set to a load corresponding to a stress the material will withstand. This spring will then give, so far as our testing is concerned, infinite life.

Unfortunately much material used is not perfect. Wire often is slightly decarburized and tests were run on such material. The photomicrograph Fig. 8 shows such a material. As received and tested with no blasting this wire was more than 5000 pounds per square inch below the normal fatigue range. The tests were not as uniform as on good wire but no run was more than 10,000 pounds per square inch below the standard wire. The value taken for this steel was 20,000 to 88,000 pounds per square inch. Springs were shot blasted with both sizes of shot. The actual result again came out the same with both shot sizes for ten million cycles, viz., 20,000 to 115,000 pounds per square inch, a loss due to the ferrite of 20,000 pounds per square inch after blasting. In this case, however, the springs that broke due to overstressing lasted longer when heavier shot was employed in contradiction to the good wire of the same size. This indicates that poor wire cannot be improved as great a percentage as

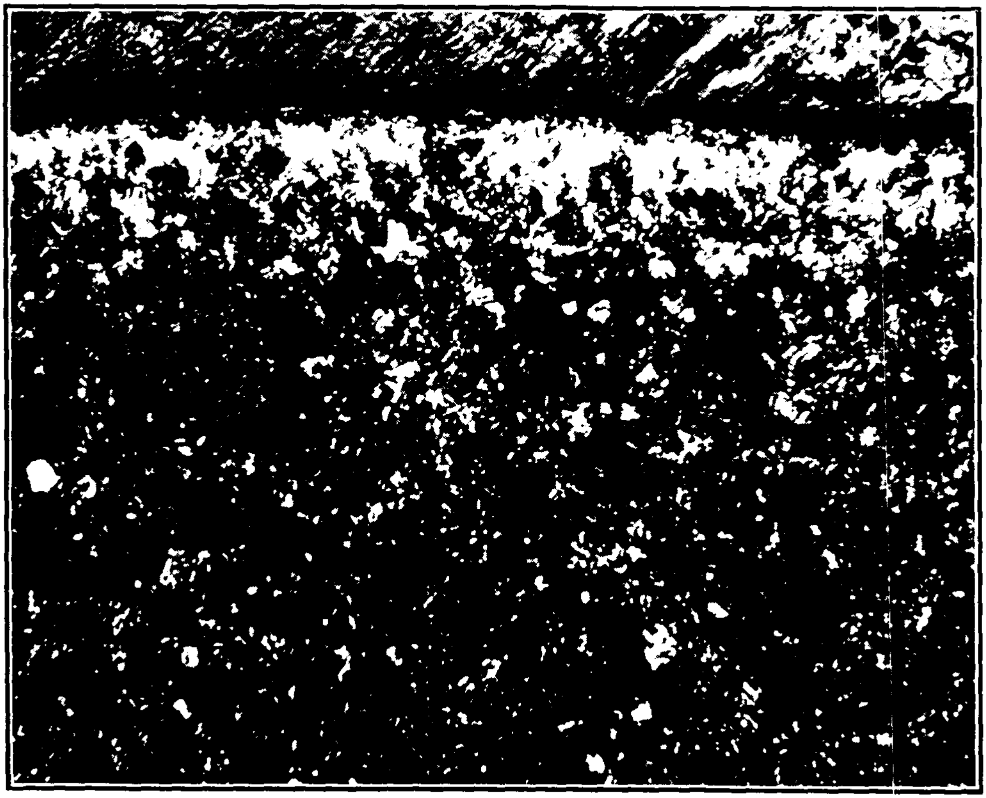

Fig. 8 Decarburized Valve Spring Wire.

sound material. The comparative results between large and small shot on this steel are logical if one pictures the larger shot carrying enough energy to cold work the steel through the decarburized surface. On the better steel this was not necessary. The small shot which cold-worked sufficiently and roughened less was the better until larger wire with lower tensile strength was used. Then the larger shot began to have more effect.

Experiments with softer shot or shot that was heated to reduce its hardness gave on sound wire the same fatigue values despite the fact that the surface appeared smoother. Examination under the binocular microscope showed enough larger pits from the blasting so that despite the visual appearance the surface itself was not for practical purposes very much altered.

Tests on springs made of defective wire have shown that no improvement results from shot blasting if seams or hairlines are present. On wire that is badly gouged, either by the wire maker or the spring producer, the shot blasting apparently has not reduced stress concentration or increased life to any great extent. With scratches round enough at the bottom (as most mechanical scratches are) a normal increase in endurance was obtained by shot blasting. Scratches up to ¼ of 1/1000 inch deep can be removed, but except for this and the improved looks of the part, no shot blasting is of help. The process will not be a cure for either defective steel or manufacturing methods.

As a result of years of testing we believe that on wire sizes less than 0.207 inch the following table shows the effect of the shot blasting accurately. The use of the highest stresses is not advised because the springs will set, or lose load to some extent, which would depend on the temperature to which the springs are exposed. No runs were made at temperatures above atmospheric and but few tests were continued beyond ten million cycles. On phosphor bronze or nonferrous metals with indefinite fatigue ranges this must be considered in design. Table I is based on results obtained using wire size 0.148 inch.

On wire sizes larger than $\frac{7}{32}$ inch, gains have been made in the endurance of the springs. The stress range does not increase in as great a percentage however. These springs have in the most part no great call for a real endurance range. They are used at stresses which will break them in time, but the number of stress applications in the life of the unit is less than they will withstand. Often increasing the

Table I

Material	Normal Stress Range Pounds Per Square Inch	Shot Blasted Stress Range Pounds Per Square Inch
Valve Spring Wire	20,000 to 95,000	20,000 to 135,000
Music Wire S.A.E. 1095	20,000 to 90,000	20,000 to 135,000
9260 S.A.E.		
6150 S.A.E.		
Electric Furnace	20,000 to 90,000	20,000 to 135,000
18-8 Stainless	20,000 to 65,000	20,000 to 110,000
13-2 Stainless	20,000 to 80,000	20,000 to 120,000
Phosphor Bronze S.A.E. 81	20,000 to 35,000	20,000 to 50,000

available stress range of the part 20 per cent will so increase the number of stress applications before breakage that the design becomes a success instead of a failure. Thus by shot blasting, coiled automotive chassis springs may now be designed up to the elastic limit since trouble will be encountered not by breakage but by loss of load due to the spring not returning to its original length. In 1934 this was not so; springs were stressed lower to avoid breakage since shot blasting machines were not designed to handle these springs. It must be realized that the increase in life of the part may be increased several hundred per cent with but a small percentage of increase in fatigue life.

This paper has dealt with coiled springs, but the process can be applied to many parts. Thus in clutches using Belleville washers the shot blast has provided safety never before enjoyed. It may be used on torsion bars, base of gear teeth, axle shafts, in fact, any highly stressed part if the surface does not need to be exceptionally smooth.

The Detroit Steel Products Company, through Mr. S. Hess, their Chief Engineer, reports increase of 3.64 times in the life of leaf springs shot blasted on the tension side. These springs, made of hot-rolled steel, were stressed from 42,560 to 121,000 pounds per square inch. As the springs are satisfactory without blasting, the process would allow less leaves to be used for the same life with consequent saving in weight.

The results we have presented can be summarized as follows:

1. Shot blasting markedly increases the fatigue life of metal parts.

2. This is a surface phenomenon which can be removed by heating.

3. The use of alloy steel, from a fatigue point of view, is not necessary in fabricating many parts.

4. Shot blasting is no cure-all for poor steel, poor design, or poor manufacturing processes.

5. Properly applied shot blasting should save weight by allowing the use of higher stresses.

6. A perfectly smooth surface is not necessarily the best surface to resist fatigue.

ACKNOWLEDGMENTS

This paper is a contribution of the laboratory of Barnes-Gibson-Raymond Division and not of any one person. The results cover a decade of testing and are drawn from hundreds of fatigue tests. In particular, A. C. Stenhouse, G. D. Wilson and Glen Brookes have contributed much to this work. It is hoped others will carry on the work, testing sections and parts for which we have no equipment.

THE AUTHOR

F. P. ZIMMERLI

F. P. ZIMMERLI was graduated from the University of Michigan with B.S.E. degree in 1917, M.S.E. in 1920, and degree of metallurgical engineering in 1934. He taught metallurgy at the University of Michigan for two years; was associated with the Solvay Process Co. for one year; one year with the metallurgical department of Dodge Brothers; five years metallurgist of Rickenbacker Automobile Co.; and thirteen years chief engineer of Barnes-Gibson-Raymond Division of Associated Spring Corp.

DISCUSSION

Written Discussion: By W. L. R. Steele, chief engineer, coil spring department, Spring Division, Eaton Manufacturing Co., Detroit.

Mr. Zimmerli is to be complimented upon a valuable contribution to a subject which has not yet received the full appreciation it merits. The six points so aptly summarized in conclusion by Mr. Zimmerli are in substantial agreement with the results secured in an extensive development program with which the writer has been engaged.

In obtaining his endurance data Mr. Zimmerli rejects the results obtained from any run if there is any evidence to indicate that the material has failed through some condition other than fatigue induced by excessive stresses. Such practice may be advisable to a degree depending upon the purpose of the test, but it must be noted that rejected runs as described tend to idealize the results.

Mr. Zimmerli's remarks as to the effects of the duration of treatment and of the number of springs treated at one time are of special interest. Uniform, dependable results from shot treatment are dependent upon the control of the time to which any particular spring is exposed to the shot stream, upon the control of the manner in which the spring is impinged by the shot stream, and upon the condition of the shot present in the machine at any particular time. It has been our experience that the first and the second of these controls cannot be obtained within accurate limits by the equipment Mr. Zimmerli describes because the treatment of any particular spring in the tumbling mass of springs at which the shot is impelled depends upon probability and chance.

It is also interesting to note that Mr. Zimmerli concludes that the effect of the shot treatment is due to cold work. We would like to ask Mr. Zimmerli if he believes the effect to be due to the superficial hardness or to the residual stresses set up by the cold work.

The writer believes that the treatment induces a shallow layer of residual compression stresses of relatively high order on the surface of the treated material. In the case of springs such as valve springs these residual compression stresses reduce the tension principal stresses and proportionately increase the compression principal stresses which are the shear stress components. According to this analysis the maximum shear stress under load is not affected by the treatment, the benefits being due chiefly to the decrease in the tension principal stresses.

The results Mr. Zimmerli reports for leaf springs are to be expected, and it should be emphasized that these results were secured when the leaves were shot treated on the tension side. It is of interest to note that the fatigue life of leaf springs shot treated on the tension side only is substantially greater than that of springs shot treated on both the tension and the compression sides.

Written Discussion: By J. G. Gagnon, chief metallurgist, Hudson Motor Car Co., Detroit.

I believe the author has well written and placed before the profession a paper that is bound to bring out much activity.

The Hudson Motor Car Company has viewed the effects of shot blasting over a period of several years with increased interest and approval.

For the past five years, we have taken advantage of this metallurgical advance by shot blasting such important car parts as axle shafts, connecting rods, steering arms, center arms, support arms and a few others with the result that fatigue failures are almost a thing of the past. In our application the time has ranged from 20 to 35 minutes; the air pressure 80 to 95 pounds, and the shot size approximately forty-three thousandths of an inch. In the case of important springs, their life has been increased materially, and with the addition of a cadmium plating operation, valve spring failures are an unknown quantity.

However, to my mind there is one important consideration on which the paper has not touched and that is—of standardizing the present art to a more exact science.

In the case of compression springs, since the inner fibers are stressed the most, why should not the inside of the spring receive the major attention? It appears to one that, assuming some measure of energy transfer per unit could be adopted, it would be necessary to adopt empirical formulae for each spring anyhow, due to the energy not being used in all cases to accomplish maximum results.

As an illustration, the maximum effect of shot blasting is dependent on the wire size (or openings between coils, permitting shot volume to enter), shot size and where and how the shot strikes the surface.

However, in the case of other units such as axle shafts, could it not be possible to determine the energy per unit surface exposed that is necessary to correctly shot blast a given steel of a definite hardness.

If some control is not devised, empirical figures will have to be determined on each part, which means fatique testing and consequently slow usage of a new and distinct metallurgical advance.

On page 272, the suggestion is made that—the process "may be used on any highly stressed part if the surface does not need to be exceptionally smooth".

Fig. 5 shows the surface and indicates, from rough measurements, that the shot blast effect extends in three or four thousandths of an inch, of this the roughened surface is not more than five to seventy-five ten-thousandths of an inch. If this condition holds true, why could not the life of parts be increased by shot blasting and grinding smooth later?

Written Discussion: By G. L. Kehl, United States Steel Corporation Research Laboratory, Kearny, N. J.

The investigation by Mr. Zimmerli is to be commended as he has shown that small machine parts, subjected to vibratory stresses when in service, can be strengthened commercially by means of shot blasting.

A similar investigation by Frye and Kehl[2] showed that blasting flat wire fatigue specimens, with round steel shot, improved the fatigue properties considerably, and that in this respect steel shot was superior to either sand or steel grit, or a mixture of sand dust and crushed carborundum.

It is commonly believed that work hardening of the surface of a metal by any means, such as shot blasting, will improve fatigue properties. This procedure introduces a counteracting effect, namely, a lowering of the fatigue strength by forming an irregular notched surface. Which of these opposed effects predominates will depend upon a number of factors, some of which are the size and shape of blasting particle, the velocity of impingement, and the angle at which the stream of blasted particles hits the surface of the material. It would be interesting to know whether Mr. Zimmerli has considered the influence of the blasting angle and if so, whether any attempt was made to control this angle from one specimen to another..

As Mr. Zimmerli points out, "a perfectly smooth surface is not necessarily the best surface to resist fatigue." This is true provided the original fatigue strength of the material is improved by some process, such as shot blasting, to a greater degree than it is lowered by the presence of a notched or pitted surface. A polished surface which is apparently free from surface defects may have concealed beneath the flowed surface metal any number of pits or scratches deleterious to fatigue strength. A truly polished surface, however, free from this defect, will show better fatigue properties than those of the same material, in the same structural condition, having an irregular surface.

Not only is it possible for the fatigue strength to be influenced by the factors already mentioned, but it may be lowered considerably by embrittlement of the surface due to excessive work hardening. In the final product, however, this embrittlement can be avoided by controlling the blasting technique, and if present, it can be eliminated to the desired degree by appropriate heat treatment.

Unfortunately, no hardness measurements were made as a measure of the degree of work hardening imparted to each specimen. Mr. Zimmerli includes a photomicrograph (Fig. 5) of one specimen purporting to show the surface condition of the material after blasting, but it does not show convincingly the extent or depth of the work hardened layer. It would be interesting to know if he observed any deformation or warping of the specimens due to the introduction or relief of internal stresses by the blasting process.

Oral Discussion

T. G. **Harvey**:[3] In some recent work in our laboratory where some S.A.E. 1035 specimens were cold-worked and the endurance properties studied, it was found that heating to 600 degrees Fahr. increased the endurance which the cold work had already increased, that is, further increased the endurance. This fact was noticed in this chart which the author gave in one of his figures. An explanation of this would be very much appreciated if one can be given.

Mr. Zimmerli: In heating a cold drawn piece of music wire the Rockwell reading will rise, at 425 degrees Fahr. reaching a maximum, and then

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[2] J. H. Frye and G. L. Kehl, "The Fatigue Resistance of Steel As Affected by Some Cleaning Methods," TRANSACTIONS, American Society for Metals, Vol. 26, 1938, p. 192.

[3] Graduate student, University of Wisconsin, Madison, Wisconsin.

drop off. I do not think these stresses are the same as the compressive stresses the blasting gives to the steel.

H. B. KNOWLTON:[4] I would like to ask the speaker concerning the size of shot that is used. What is the smallest sized shot he has found that will work satisfactorily? Also if he has worked on small wire springs, say about 0.060-0.070 inch in diameter?

We should also like to ask if the shot blasting of springs affects their ability to be successfully chrome-plated?

MR. ZIMMERLI: The smallest size of shot used was $\frac{1}{64}$ of an inch in diameter. We change the size of shot somewhat with the pitch between the coils of the springs because the inside of the springs must be blasted. The smallest springs we are blasting now are of 0.054 inch wire, about $\frac{7}{32}$ inch O.D. and 1¼ inch long.

As far as the chrome plating is concerned, if a piece of steel is shot blasted and subsequently plated it often takes on a fuzzy deposit. One thing we have done is to sand blast them lightly after they are shot blasted. It seems that you can plate a little better.

MR. KNOWLTON: Would burnishing help?

MR. ZIMMERLI: Burnishing would be all right. From then on in our practice, since we do not run a plating department, we send them over to our source. They usually tumble them in water with, I think, sand or something to polish them up a little better before they go into plating barrels. After plating we heat to remove possible embrittlement.

Author's Reply

We were indeed glad to obtain Mr. Steele's reaction to our paper. We believe that the rejection of material with metallurgical flaws is the best testing procedure. For our purpose, which was among other things to investigate the shot blasting of various materials on comparable bases, it was the only course. No one can say two flaws are equal in different materials nor can any one guess how much a seam might reduce the fatigue limit.

It is admitted our results are optimum ones but they do have a common denominator and are therefore comparable among themselves.

We agree with Mr. Steele that uniform results depend on uniform treatment and on larger springs, like those used as suspension springs for automobiles, the use of special blasting machines during the last few years has been a decided advance. These machines rotate the spring on its axis and aim the shot to hit the inside of the coil where the highest stress is located. On other types of work many special machines are in use. For the general run of small springs we have obtained good results with our equipment and the data presented was obtained in them. Test springs were blasted at the same time with production springs.

Mr. Steele's question regarding the cause of this effect is interesting and timely. We believe we have both a hardening effect and residual stresses as a result of shot blasting. Certainly when a piece of flat steel can be treated

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[4] Metallurgist, International Harvester Co., Chicago, Ill.

so as to bend it one way or another, depending on which side is exposed to the shot, we must have stresses imposed within the part exceeding the elastic limit of the material.

The leaf springs reported on are a product our company does not fabricate and we are glad to see Mr. Steele in such substantial agreement.

Mr. Gagnon's comments are well founded and we are glad to know of his commercial use of the process on parts other than springs, which are our chief interest. The standardization of shot blasting is an ideal every one should welcome. This problem would form excellent material for some University research department. Perhaps some etching reagent could be devised. The inclusion of a standard test piece in the parts being blasted would form an empirical check up on the process. To date we have no accurate method except fatigue testing. The suggestion advanced to shot blast and grind is undoubtedly an excellent one. We have no results or data regarding such a procedure at this time.

The author is in agreement in general with all of Mr. Kehl's statements. We are sorry to inform him that we cannot control the blasting angle but instead blasted so long a time the work was blasted from all angles. No length of time we have tested, viz., up to two hours shot blast time, when reheated afterward to 450 degrees Fahr. has shown us a brittle product. We have no data on longer times.

Mr. Kehl is unfortunately correct regarding the reproduction of the picture of the surface of a shot blasted spring. Visual examination is somewhat better and we can show depths of effect down 0.004 inch. This does not mean there is no influence which the microscope did not show us using a nitric acid etch. It is quite conceivable that the effect goes farther.

We have not been able to obtain accurate hardness measurements on the rough shot blasted surface and cannot give Mr. Kehl this data.

In answer to the last question, in general coiled springs increase in length and flat springs will bow when shot blasted. In fact, the free position of flat springs can be markedly altered by proper control of shot blasting.

The author wishes to thank all those who have contributed to this discussion. In calling this process to the attention of metallurgists it is earnestly hoped that many others will take over where this paper left off. The development of this process and its industrial application will in our opinion be a great step forward in industrial metallurgy. New fields are now awaiting exploration and many steels can be put to new uses.