1945001

Mechanical And Metallurgical Advantages Of Shot Peening

. . . An engineering appraisal of the technical and economic utility of compressing the surface layers of design members as a means of greatly improving their fatigue resistance. In this first section of a two-part article, the author details the history of shot peening, describes the treatment of coil and leaf springs, sandblasting effect on fatigue, tempering after peening, and the peening of torsion springs and drive shafts.

By O. J. HORGER

Head of Railway Engineering and Research, Timken Roller Bearing Co., Canton, Ohio

POSTWAR problems in equipment design will be influenced by many practices extensively applied during the war. The benefits from some of these practices are so outstanding that competitive conditions in peacetime equipment design will demand a new appraisal by engineers as to the technical and economic factors of the strength-weight ratio, space, and cost. The process of compressing the surface layer of design members, such as shot peening, offers one means of improving these factors on the basis of its significant application to wartime and prewar equipment.

Most equipment is subjected to dynamic loading or repeated stressing of the design members, and in such cases the process of shot peening has contributed much toward improving fatigue resistance. In fact, merely adding the operation of shot peening to machinery and ordnance parts has often meant the difference between failure and successful performance in service. Outstanding examples will be presented illustrating the manner and benefits by which these technical developments in shot peening and other forms of cold working the surface are being applied to various types of design members.

Fatigue failure generally initiates at the surface where the stress is often greatest and boundary conditions unfavorable. Therefore it is only natural that consideration be given to means of preparing and improving this surface layer. Increasing recognition is being given to shot peening or other means of cold working as a surface treatment which not only (a) increases fatigue resistance but which in some instances has simultaneously eliminated the (b) necessity for polishing and (c) even machining the surface after heat treatment and yet serve as a means of (d) cleaning or descaling. Obtaining maximum fatigue resistance by shot peening presumes a knowledge of the proper kind and intensity of blast upon the member and how various materials, surface conditions, and shapes of design members respond to cold working. Demands for the commercial application of shot peening have been so great that its requirements have much exceeded knowledge of fundamental factors controlling the process. An analysis of the history surrounding this process indicates that about 10 years have elapsed since the time that the beneficial effects of surface cold working were first given technical recognition.

The American spring industry was the first to make practical application

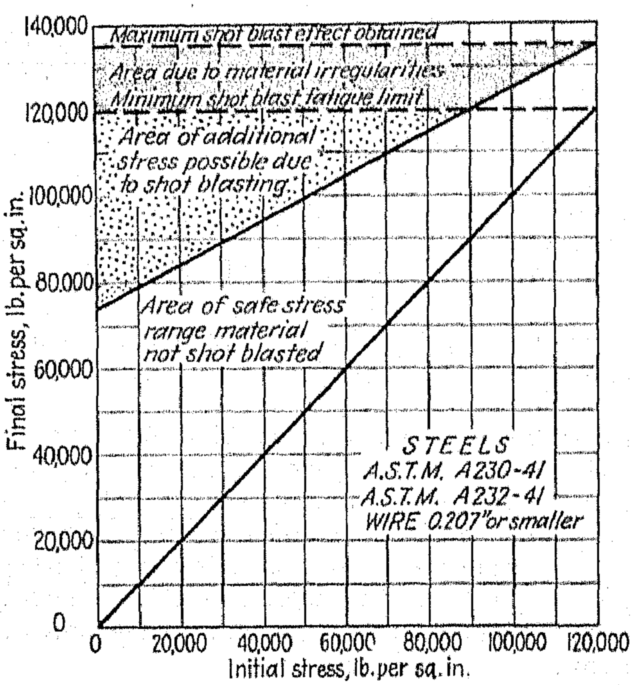


FIG. 1 — Modified Goodman diagram showing greater allowable stresses permitted on shot peened springs of pretempered wire (Gibson Co.).

1945001

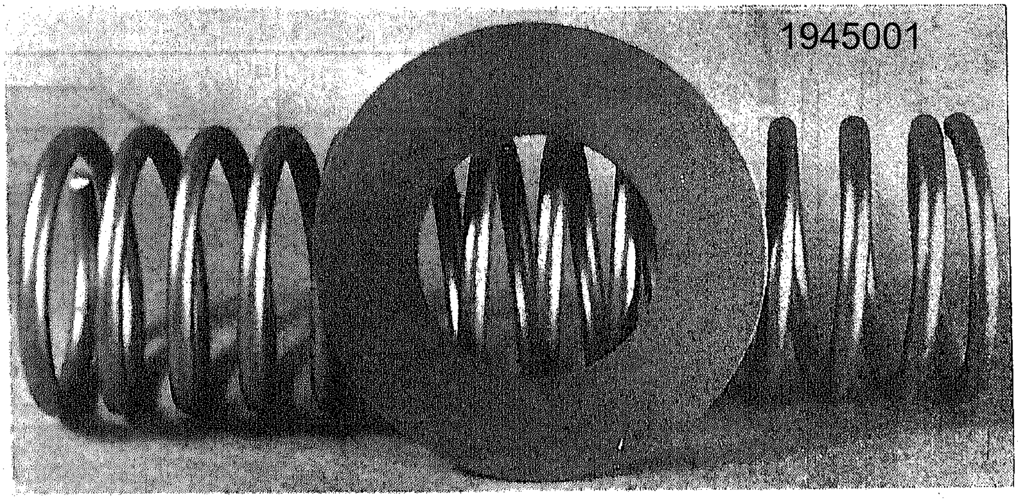


FIG. 2—Shot peened coil and Belleville washer springs. (Zimmerli).

of shot peening. Zimmerli[a] was apparently the first to publish technical papers[1] on shot peened valve springs, and stated that in 1929 the company with which he was associated sent out the first production springs in this country shot blasted to increase fatigue strength. His progress was difficult because he describes it by saying: "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." Steele[b] also utilized shot blasting on production springs[2]. Gagnon[c] stated[3] that since 1935 advantage was taken of this metallurgical advance by shot blasting such important automobile car parts as axle shafts, connecting rods, steering arms, center arms, support arms and a few others with the result that fatigue failures were almost a thing of the past. Clutch spring discs for Chevrolet[4] would not work until they were shot blasted.

Almen[d] has devoted much effort to the development and application of shot peening to different kinds of machine elements, some of which is published in available literature[5]. He is acting as a centralized authority for assisting manufacturers engaged in the war effort to improve the fatigue resistance of their product by shot peening. His experiences have made him an outstanding authority; other investigators all concur with his findings as to the marked improvement in fatigue resistance obtained through shot peening, but some disagree as to the best means of accomplishing this and the reasons for such improvement. Exceedingly little data have been released in available publications regarding the merits of shot peening

[a] *Chief engineer, Barnes-Gibson-Raymond Division of Associated Spring Corp.*

[b] *Chief engineer, Spring Division, Eaton Mfg. Co.*

[c] *Chief metallurgist, Hudson Motor Car Co.*

[d] *Head of Mechanical Engineering Department, General Motors Research Laboratory.*

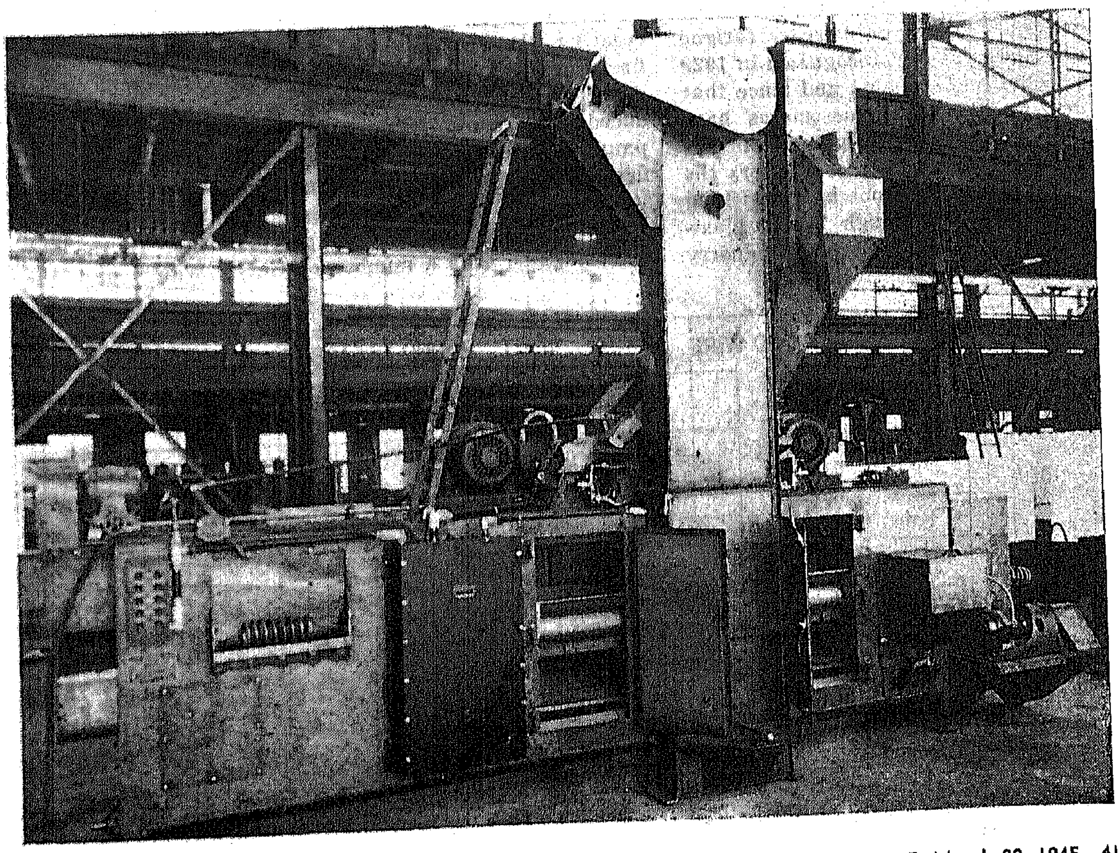


FIG. 3 — Wheelabrator unit for peening larger coil springs.

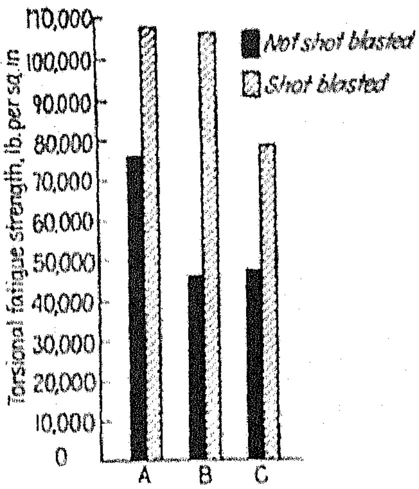


FIG. 4—Increase in fatigue strength of helical springs by shot blasting (by Lupfert) oil quenched and tempered steel wire 0.118 in. diameter with tensile strength 205,000 to 235,000 lb. per sq. in.—(a) without surface defects, (b) with small surface defects and (c) with surface laps.

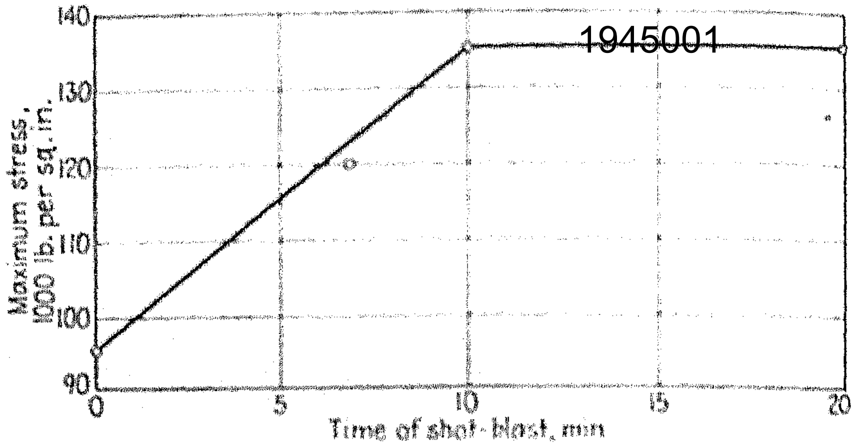


FIG. 5—Effect of time in shot blast on test springs: 1 7/32 in. O. D. coil, 1/64 in. or 3/64 in. shot size, minimum stress 20,000 lb. per sq. in., heat 20 min. at 500 deg. F. after shot-blast. (Zimmerli.)

but many investigators have made fatigue tests on actual production parts and laboratory specimens. While much of these data remain restricted until after the war there are numerous cases which may be cited to stimulate still further interest and appraise this beneficial process in terms of present and post war products.

Practical production applications outlined above were supported by technical developments in various laboratories in several different countries. The beneficial influence of surface cold working to increase fatigue resistance was first recognized in 1929 by Foppl[8] in Germany, and since that time Foppl and his associates have published at least 50 papers on this subject. In most of these papers the cold working was done by burnishing rollers, and although shot blasting was discussed, German industry lagged much behind American industry in its practical application to production parts. Foppl[9] stated in 1942 that THE IRON AGE[9] in 1930 was the first to publish the results of his findings in America and that this publication made a greater impression in America than the many papers he and his co-workers had issued at the same time in Germany. Evidently this process of surface cold working to improve fatigue resistance was accepted by German industry with considerable reluctance because he reported that American industry immediately recognized the importance of his new method and introduced it into practice.

He related that the blasting of valve springs, for the purpose of increasing the fatigue strength, was first employed to a large extent in America and from there was introduced in Germany by the Opel company. He recites the fact that the firm of Rochling, who patented[9] the steel shot blasting method in Germany, did little toward applying this process to springs so that a number of German companies had to import blasting machines from America. It was as late as 1942 when he wrote "recently, however, the ice seems to have broken in Germany" in referring to the use of surface compression to highly stressed parts. Wiegand[10] in 1940 wrote that the practice of shot peening valve springs was started in Germany in about 1938 using steel balls around 0.030 in. in diameter. It was only then that it became possible to increase the endurance of springs so that a fatigue fracture in a correctly manufactured valve spring seldom occurred.

In 1927 in England, however, Herbert[11] reported on hardening by "cloudbursting" parts with steel balls, for reasons other than obtaining increased fatigue resistance, but no statement can be found indicating that he recognized important increases in fatigue strength by this process. Weibel[12] in 1935 was the first to show that increased fatigue resistance could be obtained by shot blasting. In the same year Peterson and Wahl[13] and the author[14, 15] also re-

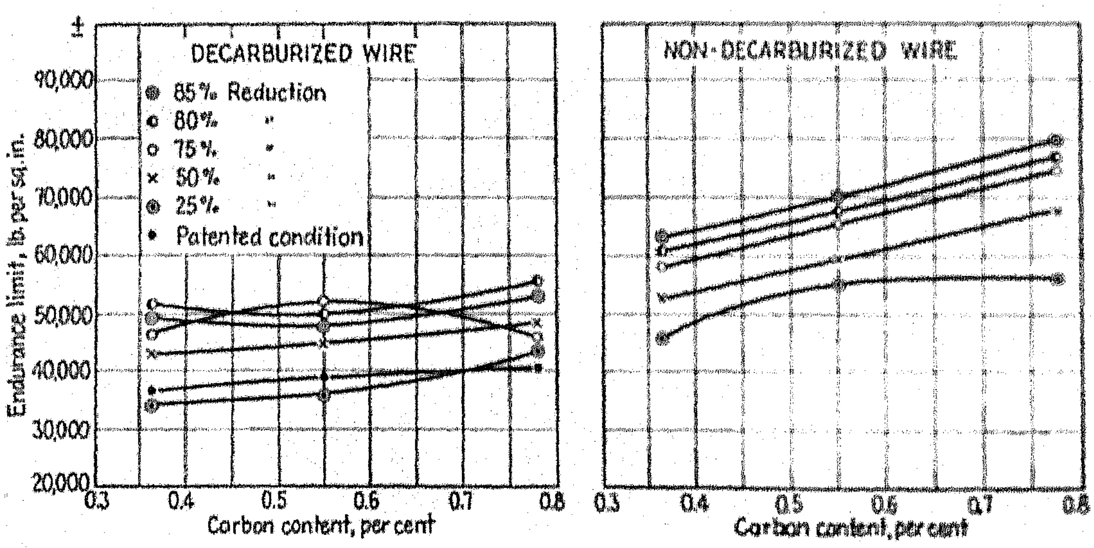


FIG. 6—Influence of carbon content and decarburized surface layer on the rotating bending fatigue strength of patented drawn wire. (Gill and Goodacre.)

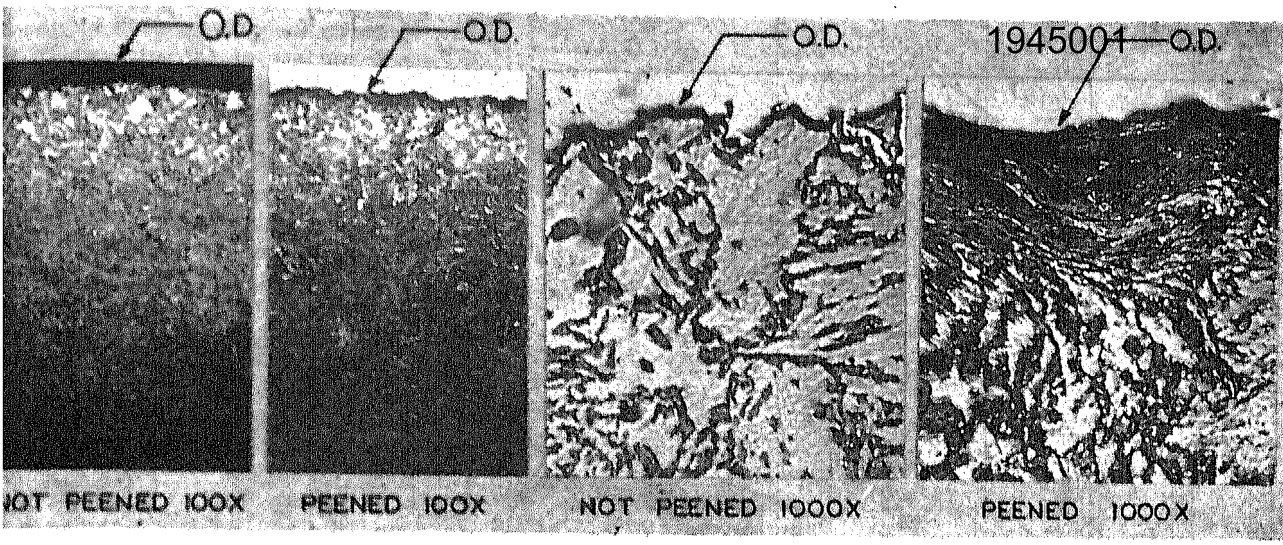


Fig. 7—Microstructure at surface before and after shot peening NE 8650 steel quenched and tempered to 444 Brinell.

rted large increases in fatigue re- tance by cold working using bur- shing rollers. The specific subject of ot blasting as it was related to im- oving fatigue properties received no rther attention in the technical liter- ure until 1938 by Frye and Kehl, ien Foppl, Zimmerli and Wie- nd published results in 1940. Re- lts of Lessells and Murray as well Mantouffel appeared in 1941. Two ditional papers appeared in 1943; men' gave results of fatigue inves- ations made on various kinds of t peened automotive parts and Lap- rt presented results of German ts. In 1944 three technical papers, and a review were presented; o a symposium on this subject was d by American Society for Metals their annual meeting.

Coil Springs Shot Peened

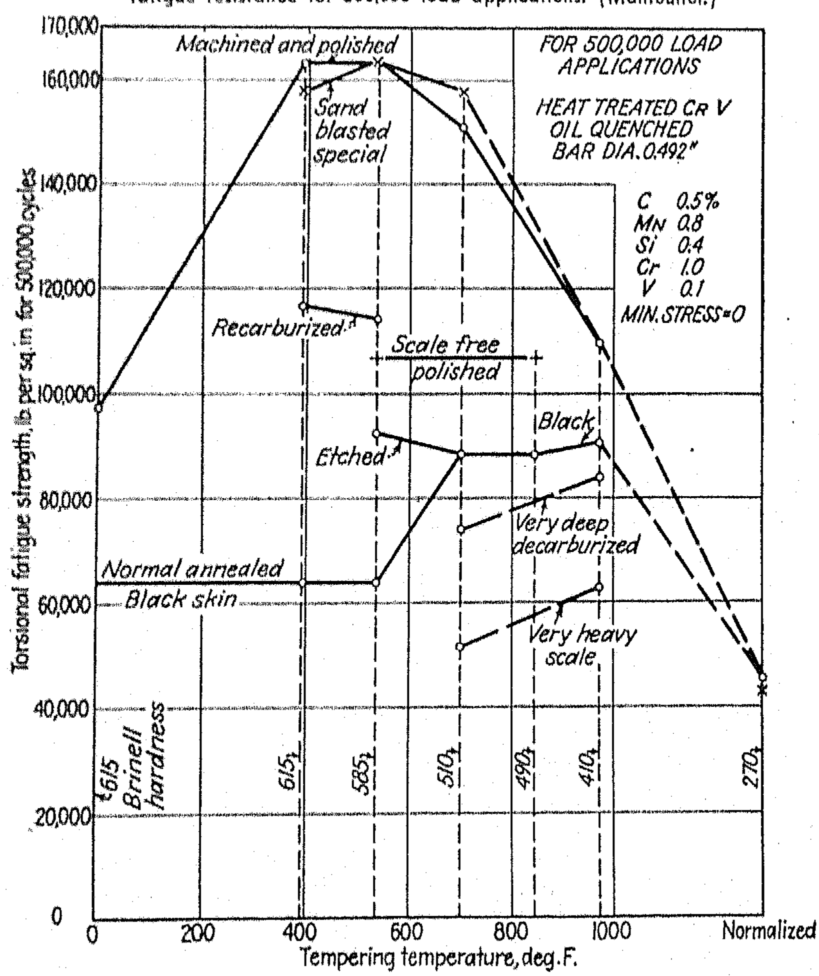
t is easily understood that the en- neer often finds it more desirable to vent fatigue fractures by increas- the dimensions than to employ mingly new methods of compress- the vulnerable surface layers. In case of springs, however, increas- the dimensions is certainly an un- isfactory method; the spring would ome more rigid and therefore im- r its characteristics as a spring. a design limitation lent encourage- nt toward the development and er wide acceptance by the spring ustry in adopting shot peening as urface treatment.

An engineering expression of the ue of shot peening coil springs of tempered wire is shown by the dified Goodman diagram in Fig. 1. re the permissible range of stress m minimum to maximum is given peened and not-peened springs, which the wire diameter does not eed 0.207 in., of plain carbon or chromium-vanadium steel of valve spring quality. The designer would interpret Fig. 1, for instance, to mean that the allowable maximum stress on a peened coil spring could be increased by the amounts shown in the Table I above that for a spring not shot peened.

Table I is based on values used for long-life springs; the stress given includes the Wahl correction factor to give the actual stress on the inner surface of the wire where it is a maximum.

Two typical shot peened springs are illustrated in Fig. 2. Coil springs are peened in production using a machine of the type shown in Fig. 3. Here the spring rotates under the shot stream

FIG. 8—Influence of surface conditions and tempering temperature upon torsional fatigue resistance for 500,000 load applications. (Mantouffel.)



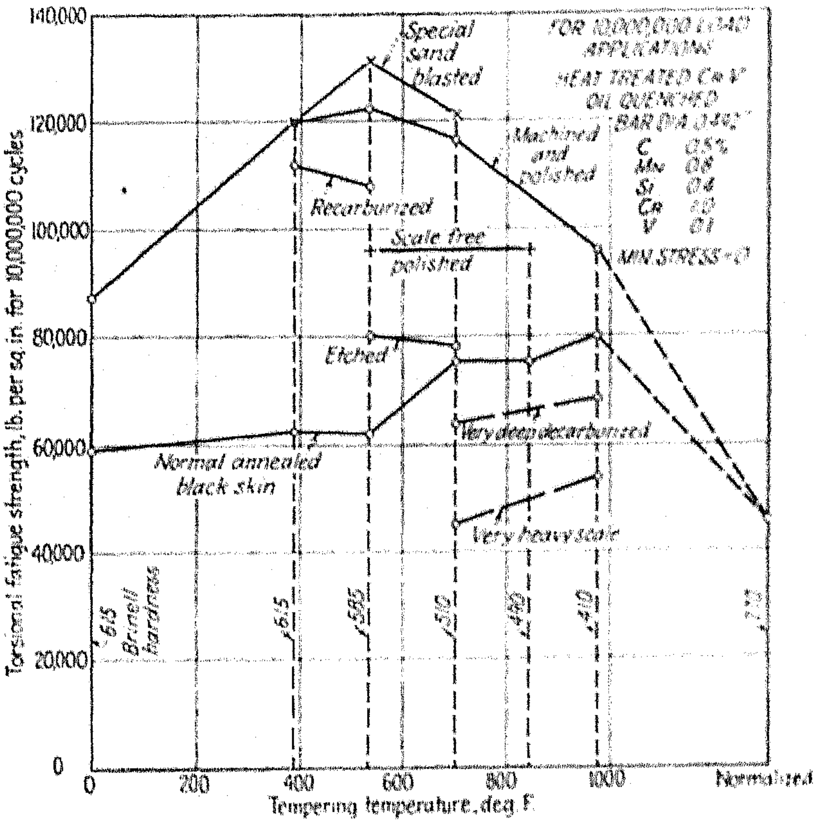


FIG. 9—Influence of surface conditions and tempering temperature upon torsional fatigue resistance for 10,000,000 load applications. (Manteuffel.)

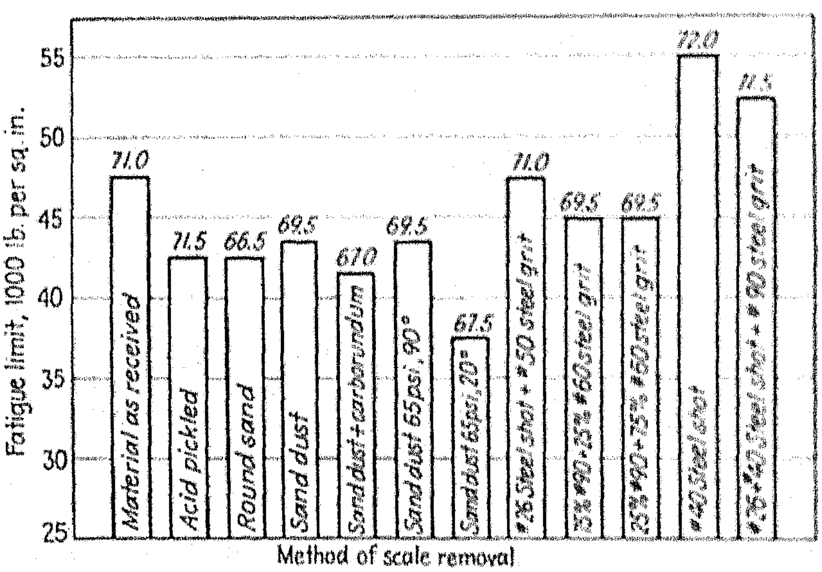


FIG. 10—Graphical presentation of fatigue limits resulting from descaling by various methods. Numbers above columns indicate superficial hardness numbers, N15. (Frye and Kehl.)

TABLE I

Increase of Allowable Maximum Stress on Non-Peened and Peened Coil Springs

Minimum Stress on Peened or Non-Peened Spring, Lb. Per Sq. In.	Maximum Stress Allowable, If Not Peened, Lb. Per Sq. In.	Lower Range of Maximum Stress Allowable, If Peened, Lb. Per Sq. In.	Minimum Increase in Stress Permitted by Peening, Per Cent
0	74,000	120,000	62
25,000	90,000	120,000	33
50,000	100,000	120,000	20
70,000	110,000	120,000	9
90,000	120,000	120,000	0

in such a manner that the shot passes between the [illegible] to hit the inside surface of the wire where the highest stress is located under service loading. Coil springs made from bar stock up through 1¼-in. diameter, and using different types of plain carbon and alloy steels are being shot peened in many plants in this country and abroad as regular production operations. In the machine shown in Fig. 3, the shot is fed into the center of a rotating wheel and then accelerated by vanes to the outer periphery of the wheel where it is discharged at considerable velocity. Other types of machines use compressed air to accelerate the shot against the coil.

Hollenrath and Bungardt[36] even used the ball head of a hammer to peen the surface of about ⅛ in. diameter drawn tension wire, and found that this operation increased the rotating bending endurance limit from 64,000 lb. per sq. in. to 79,700 lb. per sq. in., or an increase of 25 per cent. They used a plain carbon wire of 0.45 per cent C and less than 0.35 per cent Si and 0.8 per cent Mn, heat treated to 170,700 lb. per sq. in. tensile strength.

German results by Lupfert[38] in Fig. 4 indicate that the torsional fatigue resistance of spring wire may be increased by shot peening even though surface defects are present on the wire. In condition A of Fig. 4 the fatigue resistance is increased 40 per cent by peening wire having no defects. The wire in B had certain surface defects such as decarburization, flat or shallow seams and ridges and yet peening gave an increase of about 130 per cent. Wire with surface laps in C was improved 60 per cent by peening where the shot could not even penetrate to the bottom of the surface laps.

Zimmerli[1] reported that valve springs of 0.162-in. diameter wire from heat treated plain carbon steel (0.65 per cent C, 0.58 per cent Mn, about 200,000 lb. per sq. in. tensile strength) without surface decarburization or defects gave an endurance limit value of 95,000 lb. per sq. in. for non-peened springs as compared with 135,000 lb. per sq. in. when peened, or an increase of 42 per cent, as shown in Fig. 5. Slightly decarburized surface reduced the 95,000 lb. per sq. in. for non-peened springs to 85,000 to 90,000 lb. per sq. in., whereas on peened springs this ferrite layer was hardened and broken up and resulted in a reduction from 135,000 lb. per sq. in. to 115,000 lb. per sq. in. Zimmerli[1] discusses defective wire having seams or hairlines or badly gouged surface and states that shot blasting does not improve the fatigue values, but he does not submit data. He concludes that peening is no cure for either defective steel or manufacturing methods, but the data by Lupfert in Fig. 4 appears to be in variance with his findings in that certain surface defects can be rendered unharmful and the fatigue resistance increased by shot peening.

Decarburized and Peened Surfaces

Wiegand[10] reported fatigue results on valve springs made of ground wire and on shot peened springs which confirm the favorable effects of this process. The latter showed an increase of 60 per cent in the allowable stress range over that obtained for the ground springs. A mean torsional stress of 75,400 lb. per sq. in. was used in both cases, as calculated at the internal diameter of the spring, but the permissible stress range was 52,600 lb. per sq. in. for the ground springs and 79,700 lb. per sq. in. when peeened. Wire was 0.7 per cent C, 0.5 per cent Mn. and 0.3 per cent Si, and the above endurance values were based on 20 million load cycles.

A good basis exists for the manner in which a decarburized layer obscures the effect of the carbon content on fatigue strength and how it is detrimental to fatigue resistance. Gill and Goodace[27] made detailed and systematic fatigue studies on patented drawn steel wire 0.080 in. in diameter with and without decarburized surface[6]. The non-decarburized wire was obtained by grinding off the surface decarburized layer before the final drawing operation.

[6] *Decarburized skin approximately* 0.002 *in. deep.*

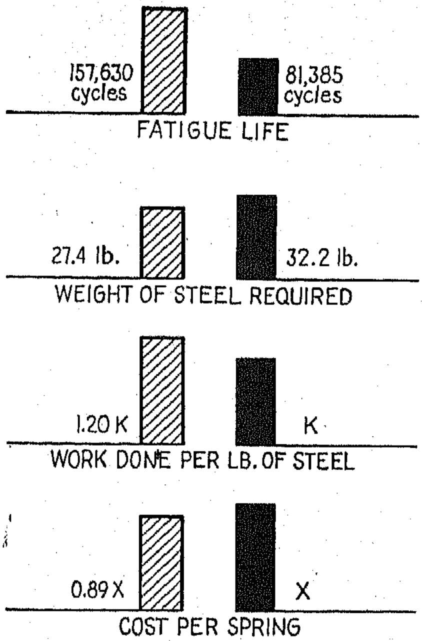


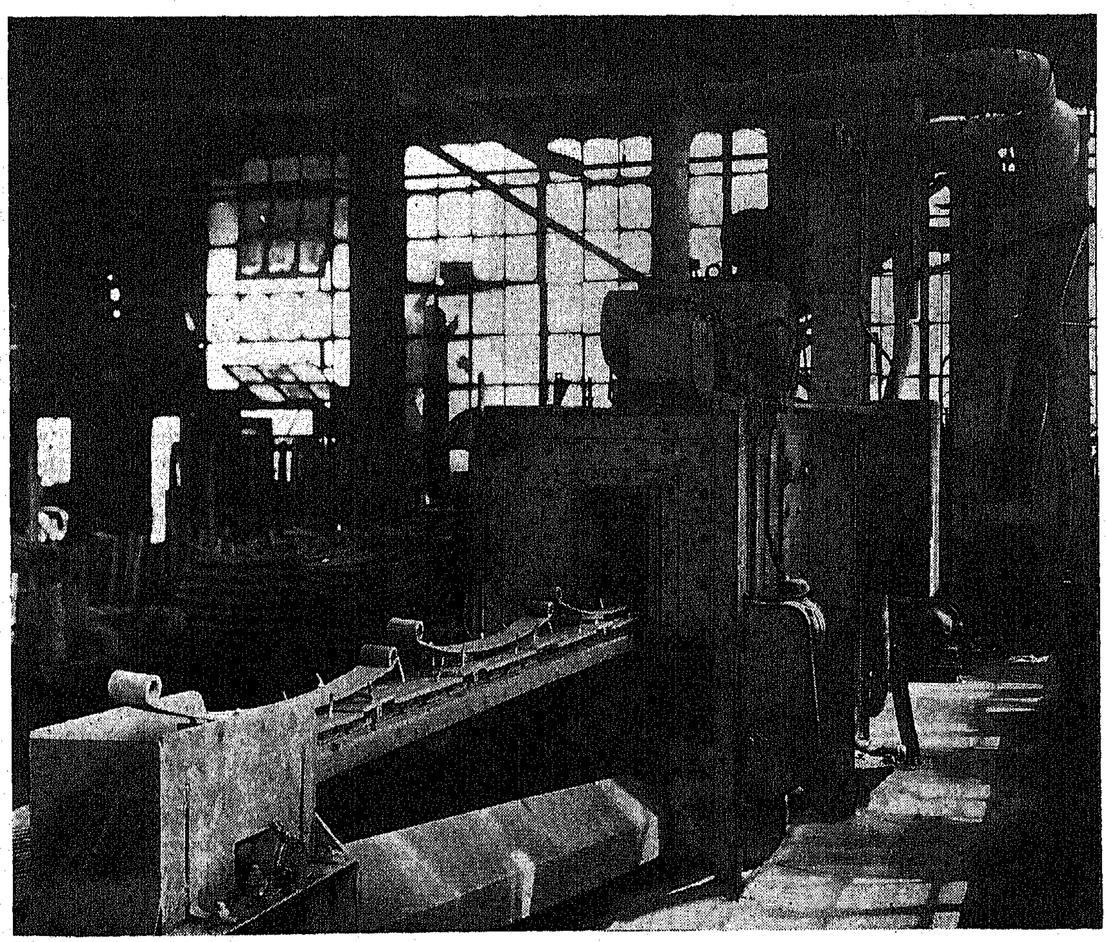
FIG. 11—Comparison data on leaf springs by Eaton. Left shows shot peened grooved section steel. Right shows conventional plain section not peened.

Their results in Fig. 6 show that the fatigue strength in reversed bending was practically independent of the carbon content when a decarburized surface layer was present; the fatigue resistance of the wires was apparently determined by the fatigue strength of the material of lower carbon content in the ferrite skin.

The case of the non-decarburized wire is also shown in Fig. 6 where the improvement in fatigue resistance increases with increasing carbon content. This is in accordance with the usual relationship which exists between carbon content and fatigue resistance. This beneficial influence on fatigue of removing the decarburized layer from members subjected to repeated stresses has been determined by many investigators [10], [26], [28], [29].

Photomicrographs in Fig. 7 illustrate the structure of the unmachined surface layer on both peened and nonpeened bars of NE 8650 steel forged to 1⅝-in. diameter and quenched and tempered. Before shot peening, the surface hardness varied between Rc 28-32 on several bars due to variable

FIG. 12—Typical peening operations on leaf springs on Wheelabrator.



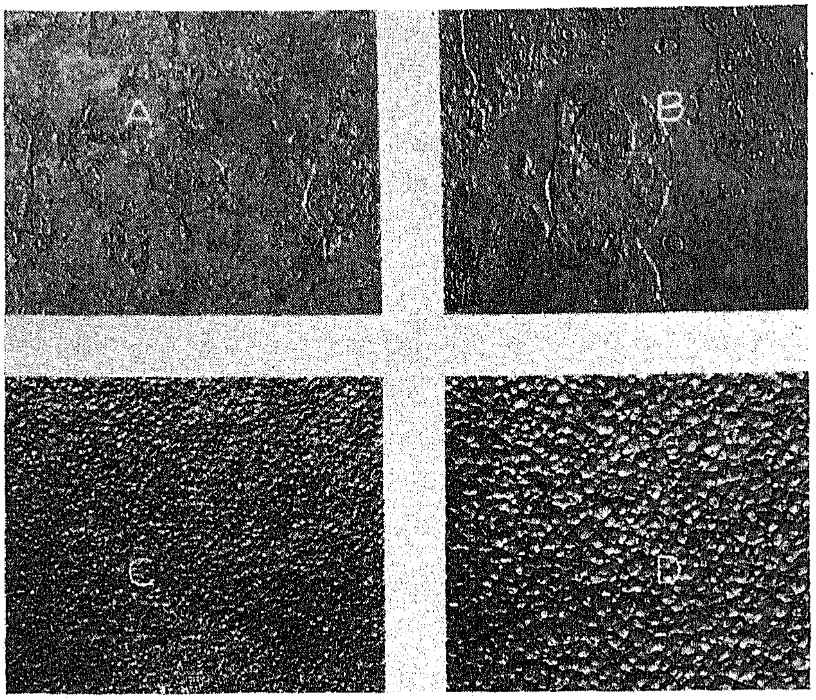
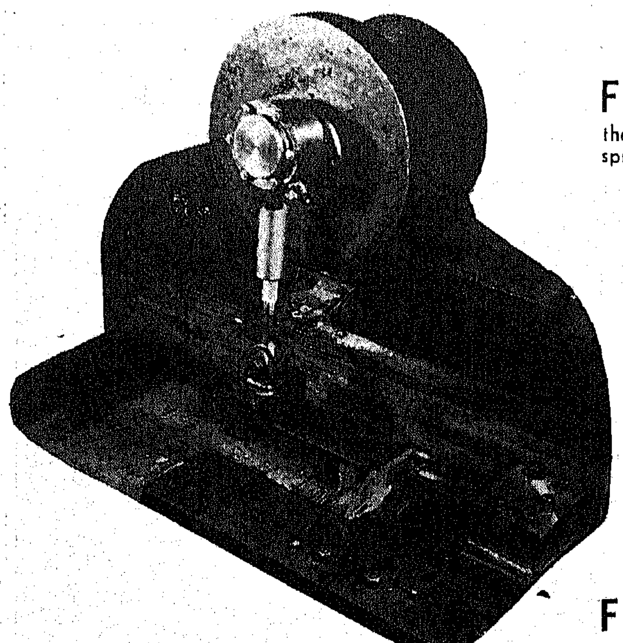


FIG. 13—Surface conditions on leaf springs, at five diameters—(a) hot rolled; (b) after heat treatment; (c) same as B after peening with 0.024-in. shot to 0.00702; and (d) same as B after peening with 0.055-in. shot to 0.02202.

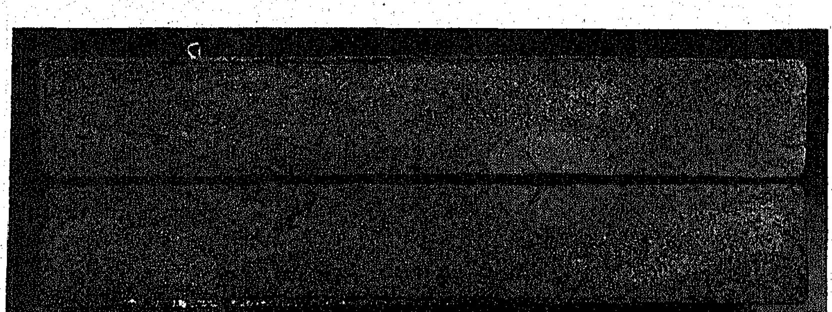


LEFT

FIG. 14 — Laboratory method of determining the fatigue resistance of a spring leaf in alternating bending.

BELOW

FIG. 15—Cross-section of spring leaf showing typical fatigue fracture.



decarburized conditions, while about ⅛ in. below the decarburized layer the hardness was Rc 41-43. Structural changes have taken place after peening and Fig. 7 indicates the grain distortion, flattening, and sealing of the grain boundaries on the immediate surface containing the ferrite layer. In this case the rotating bending endurance limit was doubled by shot peening on the unmachined forged surface.

X-ray measurements by Lessells and Murray[18] indicated the cold worked layer to extend a depth of 0.006 in. on a shot peened surface of SAE 4340 (Brinell 278) which had been previously machined and polished. Almen[5] had previously shown this same depth value by a process of removing the blasted surface skin in successive steps and noting a change in curvature. Zimmerli[1] reported positive microscopic evidence of structural differences at least 0.004 in. deep.

Sandblasting Effect on Fatigue

Manteuffel[19] published some interesting findings on the beneficial effect of sandblasting quenched and tempered chrome vanadium steel spring wire 0.492-in. in diameter. His results in Figs. 8 and 9 show how the maximum torsional fatigue resistance varies for different surface conditions and tempering temperatures. Curves in Fig. 8 apply to heavy duty springs where the desired spring life does not exceed 500,000 load applications at high stresses; if long spring life is required, then it is apparent that the allowable maximum stresses must be decreased to values given in Fig. 9. These curves are based on the minimum stress being zero.

The spring specimens, which were black after heat treatment and had a decarburized layer, were sand blasted in a special manner with standard quartz blasting sand. Fatigue results in Fig. 8 and 9 produced allowable endurance values for the sand blasted spring stock which was very comparable with the ideal values obtained after grinding off the decarburized layer and then carefully hand polishing with No. 0 paper. While the sand blasting gave the most favorable values at the three tempering temperatures and high hardness values investigated, it would be of more practical interest to have similar data at lower hardness values at which springs are often manufactured[1].

Manteuffel explained the above favorable effects of sandblasting in the following manner. The blasting removed the scale layer and the decarburized layer is partially removed and then work hardened; in doing this the surface is supposed to be damaged as little as possible and provided with favorable compressive residual stresses. Preliminary tests were made concerning different blasting conditions

[f] *The good results shown by recarburizing were obtained by heating the normally annealed spring material, having scale on the surface, in a durferrite salt bath for two hours, cooled, heated in same bath to hardening temperature, then quenched and given a temper in an air furnace. Increase in fatigue values given here by recarburizing are large compared to the relatively small increases found in similar steel and also silico-manganese spring steel treated in a molten cyanide carburizing bath by Hankins.*[30, 31]

which showed that less surface damage results with low stream pressure and grain size. It was found expedient to initially use a stream with high pressure in order to rapidly remove the detrimental surface layer and to work harden the surface and provide it with favorable compressive stresses. At the end of the blasting process the surface was smoothed by using a stream with low pressure. In this manner the detrimental influence of the surface damage could be held much lower than the favorable influences even in the case of the high hardness materials.

Frye and Kehl[16] also investigated the reversed bending fatigue strength of steel wire[g] as it is influenced by various descaling methods using sand, steel shot, and steel grit blasting. Their results in Fig. 10 were obtained on specimens cold-rolled from a heat-treated round wire rod to ⅛ x ½-in. cross-section. No surface decarburization was present on the material in the as-tested condition. Sand blasting

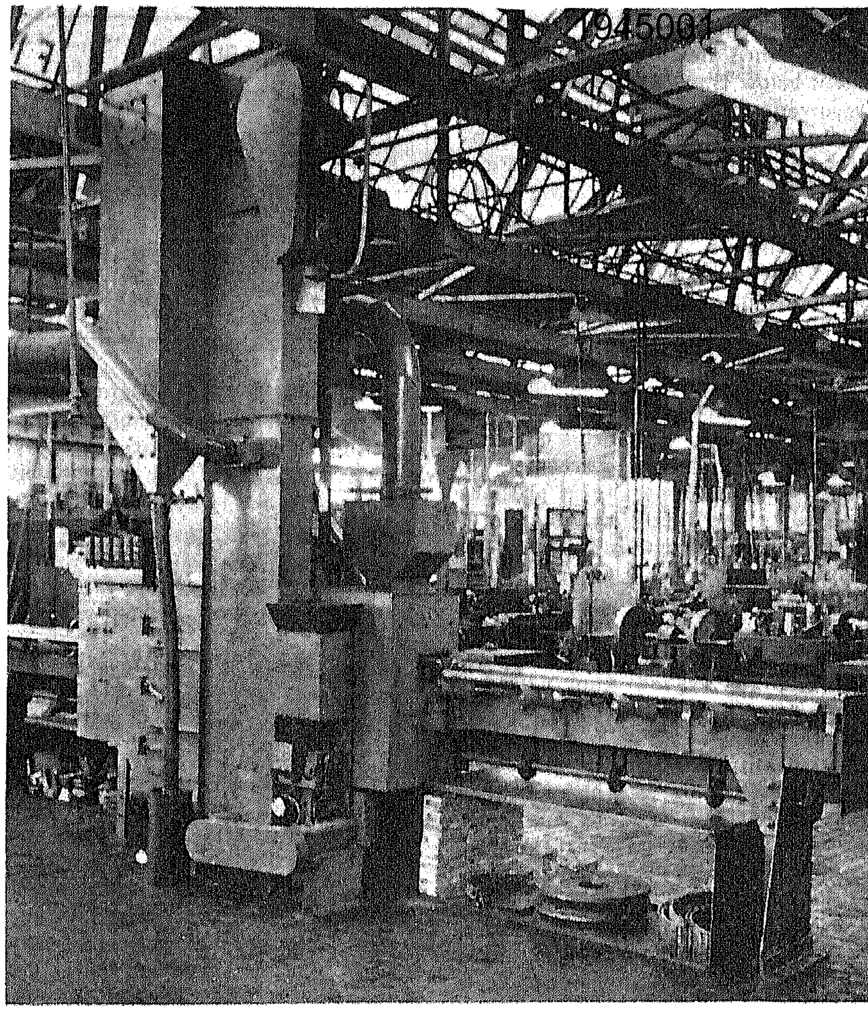


Fig. 16—Method of shot peening torsion bar springs on Wheelabrator.

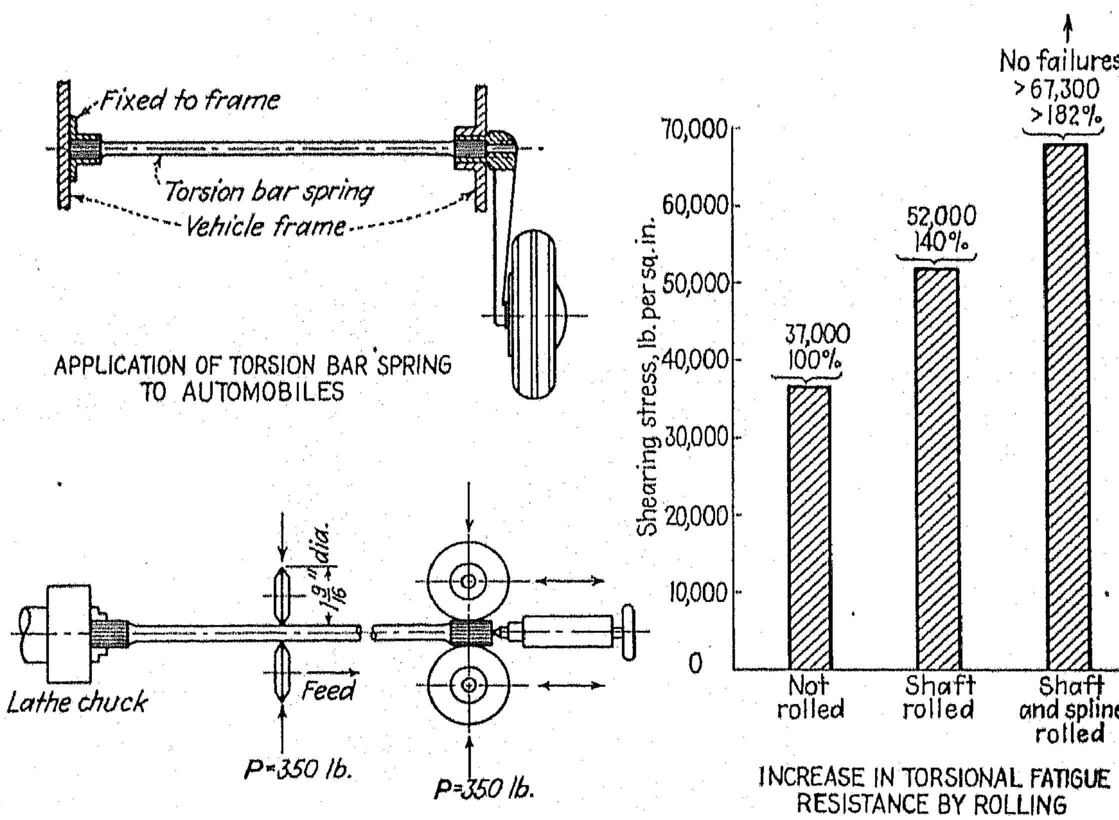


FIG. 17 — Method of rolling torsion spring. (Lippacher and Foppl.)

with three types of sand decreased the endurance lmit values about 10 per cent below that for the steel in the as-received condition.

The question arises as to why Manteuffel obtained an increase and Frye and Kehl a decrease in endurance values through sandblasting. One plausible explanation is that the hardness values, materials, and surface conditions as to decarburized layer were vastly different in the case of these two investigators. Also the blasting conditions could be different since the intensity and coverage was not specified. Foppl[7] comments on this question by stating that this disagreement is only an apparent one and is presumably due to the fact that Manteuffel used freshly delivered sand while Frye and Kehl probably used the sand longer, as is usually customary in blasting parts for cleanng operations. He points out that the original sand particles break up into finer particles in a relatively short time. Such fine sand particles exerts only a scratching or cleaning action and its detrimental influence on fatigue resistance is not sufficiently offset by the beneficial effect of cold work of the surface. He concludes that sand can only be used once and to eliminate the constant changing of sand in production it is more expedient to use steel shot.

The engineering and economic utility value of shot peening leaf springs

[8] *Plain carbon steel:* 0.54 *per cent C*, 0.60 *per cent Mn*, 115,700 *lb. per sq. in. ultimate strength*, 76,700 *lb. per sq. in. yield point*, 14.5 *per cent elongation*, 40 *per cent reduction in area, superficial Rockwell* N15-71.5. *After cold rolling to flat wire it was quenched in molten lead* 900 *deg. F. and roller straightened.*

TABLE II

Life Comparisons for Leaf Springs

Surface Treatment	Vibrations to Failure
Sand blast........	50,000
Etched...........	60,000
Shot blast.........	300,000

has been best stated[32] by Eaton in Fig. 11. Two variables of spring leaf section and shot peening are expressed in this comparison and the separate influence of each is not given. Values shown are based on an accelerated test through an 8 in. stroke, 4 in. above and below normal position and an average of four springs of each type.

It was also claimed[33] by Wallace that greater endurance is obtained if the leaves are peened on the tension side only than if they were peened on both sides. His patent states that the peened spring leaf life is at least 60 per cent greater than when not peened. He explains that the camber or height of the leaf is decreased by shot blasting and this is an indication of the favorable residual compressive stresses on the tension side. This change in camber is provided for by forming the leaf originally to a slightly greater camber.

United States Patents[9], assigned to German firm of [illegible]ing on the process of shot peening leaf springs, gave life comparison of leaf springs at shown in Table II.

With still other springs this life improvement was from 100,000 without peening to 1,000,000 vibrations with peening. It was stated that 5 sec. under a sand blast is ordinarily adequate for cleaning and smoothing purposes, but it was found that a minimum of 20 sec. under a shot stream was required for an improvement in fatigue resistance.

Zimmerli[1] reported that Detroit Steel Products obtained 3.46 times the life on shot peened leaf springs as on those not peened. The leaves were peened on the tension side only and were stressed from a minimum of 42,560 lb. per sq. in. to a maximum of 121,050 lb. per sq. in.

Production method of shot peening leaf springs is illustrated in Fig. 12 and it is not unusual to use a conveyor speed of 16 ft. per min. Conveyor speeds about three times as high have been used and while spring performance was improved it has been found that the lower speeds are more effective in increasing fatigue resistance. Typical surface conditions on the surface of 9/16 in. thick leaves at various stages of processing are shown in Fig. 13. Both the hot-rolled and heat-treated examples have a decarburized layer and this condition in combination with surface irregularities, hammered-in scale or inclusions is the major cause of the low fatigue resistance of spring steel plates. Various investigations have shown that the inherent bending fatigue resistance of various steels in the ideal machined and polished condition is 1.2 (for mild steels) to four times (for heat treated

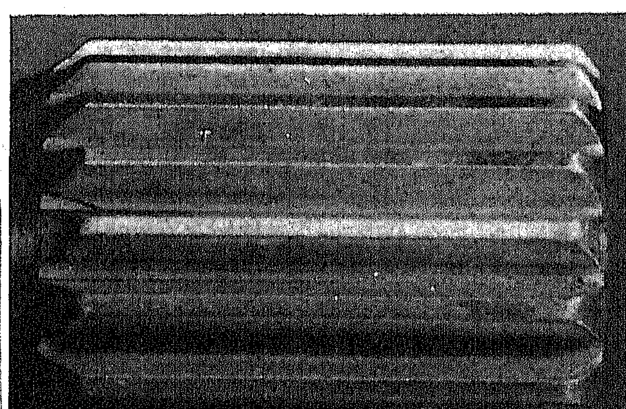
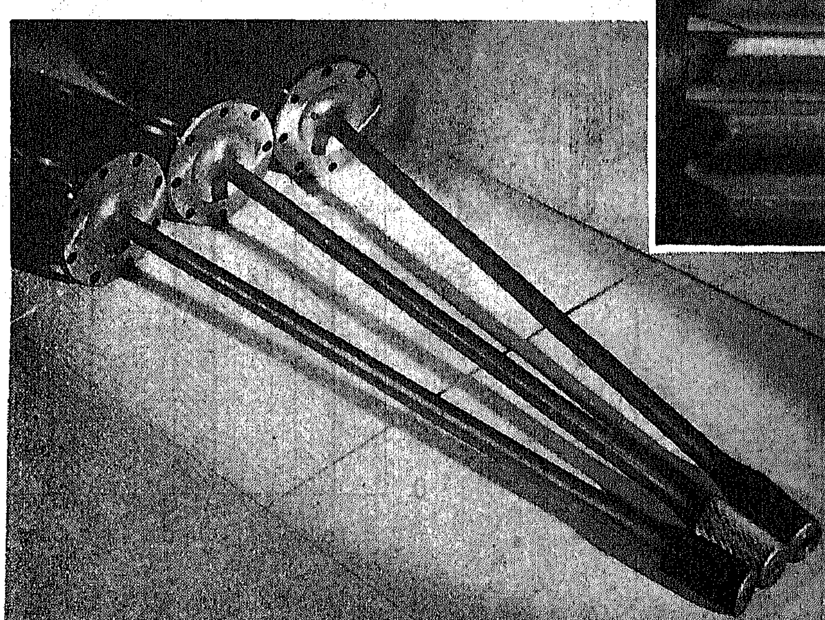


FIG. 19—Typical fatigue fracture at base of tooth on spline.

Fig. 18—Quill drive shafts shot peened. (Simon.)



spring steels) that obtained with such surface skin conditions[10], [28], [29]. On high strength forgings, however, this ratio may be as high as 7[31].

Surface appearance after shot peening is also shown in Fig. 13 for two different shot sizes. The smaller size shot is generally used. Means of investigating the improved fatigue resistance of single spring leaves by peening is shown in Fig. 14. A typical view of a leaf which has developed a fatigue fracture is indicated in Fig. 15. A small thumbnail area progresses from a point on the surface and then the fatigue crack propagates rapidly to complete fracture.

While this procedure of testing single leaves gives comparative fatigue data on different surface conditions, such data may not be necessarly translated directly into permissible stresses for the design of leaf springs. Constructional influences such as "nip" of the individual leaves, clamping in the band, friction points between the leaves, and presence of eyelets, holes, and stamped notches for leaf alignment all serve to give lower fatigue values for the complete spring as compared with that for a single leaf. Depending upon the material and hardness, the decrease in the case of complete springs with the as-rolled surface amounted to approximately 30 per cent to 50 per cent; when the spring material is annealed or quenched and then tempered at a high temperature the complete spring is only about 5 per cent to 10 per cent below that for the individual leaf[29].

Torsion Springs and Drive Shafts

Greater use is being made in America of the straight cylindrical bar torsion spring for suspension systems than heretofor although it has been in extensive use in Europe for some time. Such torsion bars are generally shot peened to increase fatigue resistance as shown in Fig. 16. The problem and its solution is similar to that already discussed for coil and leaf springs.

Improved fatigue resistance has also been shown for torsion bar springs[h] by Lippacher and Foppl[34] by means of surface rolling both the body portion and the splined ends. The results of their investigation are summarized in Fig. 17. They had considered shot peening but they evidently believed that this operation would interfere with proper engagement of the splined ends which is not considered objectionable in United States. By rolling only the body of the spring, the endurance limit was increased 40 per cent but then fatigue fracture developed in the spline and not in the body as before. The radius at the base of each spline tooth was then rolled at 353 lb. pressure with a roller having a contour radius a little less than the root radius of the spline; the flank angle of the roller was made to clear the sides of the spline and only contact the root radius so as to not interfere with the mating surfaces. When both body and spline was rolled, then no fatigue failure took place even though the alternating torque moments was 1.82 times as great as that for the conventional spring not rolled.

Simon[k] shot peens[35] quill drive shafts shown in Fig. 18 as regular production practice. A typical fatigue fracture

(CONTINUED ON PAGE 100)

Aerodynamic Turbine for Blast Furnaces

THE recent introduction of steel recuperators for heating blast-furnace blast in a continuous cycle instead of the intermittent cycle of the brick stove has achieved a considerable reduction in power consumption and has led to smaller heat losses, C. Keller and R. Ruegg report in *Stahl und Eisen*, 1944, vol. 64, March 30, pp. 201-6.

A promising possibility of further economic improvement is the application of the aerodynamic turbine as the prime mover for blast-furnace blowers. This turbine requires an air heater of similar construction to the modern steel recuperator.* The objection that gas turbines require several bulky heat exchangers to achieve a high efficiency is not valid for the air turbine, as the dimensions can be reduced considerably because of the clean working medium and the higher pressure levels employed. The air heater now has the same dimensions as a modern steam boiler of the same output.

Several plans have been outlined: (1) Where the blower is driven by an air turbine, and a combined air heater heats the blast for the furnace and the cycle air which works the turbine; in this the path of the combustion gases is divided into two. The air coming from the blower is heated in the low-temperature section and the cycle air in the high-temperature section. The high pressure employed in the air-turbine plant improves the heat transmission in the high-temperature zone of the air heater. Experience gained with a pilot plant shows that the problem of heating air to high temperatures has been solved. (2) A combination of Cowper stoves and an air-turbine-driven blower. (3) A plant in which the blower compresses the blast to a higher pressure than that required for the furnace; in this the compressed air is heated in the first stage of an air heater and then expanded to about furnace pressure in an air turbine coupled to a blower; the required additional power is produced by an aerodynamic turbine. The expanded air is then heated to the temperature required for the furnace. The advantage of this system is that the heat consumption for an equivalent volume of air is about 6 per cent lower than with scheme (1).

It would be advantageous to arrange the plants for these three plans in such a way that the air turbine is divided into high- and low-pressure stages, the low-pressure stage driving the blower at a rate varying with the required load, and the high-pressure stage driving the compressor for the cycle air. Electric power could also be generated by the air turbine if it were made large enough.

In a combined blast and cycle-air heater capable of heating 220,500 lb. of blast and 240,345 lb. of cycle air per hr. are given, the heating surface for the cycle air is about one-tenth of that for the blast. The cycle-air heater lowers the temperature of the combustion gas to the safe level necessary for the blast-heater tubes. The heating of the cycle air by the combustion gases is carried out in uniflow, which is possible because the temperature gradients between the combustion gases and the air are large and uniflow insures relatively low and evenly distributed tube temperatures. The blast-furnace blast is heated by cross-current flow. An additional burner is fitted between the two stages to provide a means of controlling the blast temperature independently of the cycle-air temperature. When heating the blast in Cowper stoves, thorough cleaning of the blast-furnace gas is necessary, whereas with the new process such careful cleaning becomes unnecessary.

*See *The Iron Age issues of April 16 and April 23, 1942, for detailed data on steel recuperator design.*

Shot Peening

1945001

(CONTINUED FROM PAGE 49)

which has initiated at the base of a spline tooth is shown in Fig. 19. This later photograph was not taken from quills of the type shown in Fig. 18 but is an example of a condition which shot peening will improve.

Tempering After Peening

The torsional and bending elastic limit values are sometimes decreased due to shot peening. This is also particularly noticeable on hard drawn carbon steel wire and may influence the set characteristics of the spring in some applications. To improve these elastic limit values a low temperature tempering treatment is applied. Zimmerli[illegible] shows in Fig. 20 how such treatment influences the fatigue instance. All the beneficial effect of peening is lost at a temperature of 825 deg. F.

Further example of a mild heat treatment was reported[illegible] on S.A.E. 1045 steel, normalized and tempered, which had been surface rolled with rollers similar to that shown in Fig. 17. After a mild temper of 525 deg. F. the rotating bending endurance limit

[illegible] *Chrome-vanadium steel quenched and tempered to R_c46. Decrease in diameter due to rolling was less than 0.0008 in.*

[illegible] *L. E. Simon, chief metallurgist, Electro-Motive Division, General Motors.*

was increased by 6 per cent and the elastic limit improved over that obtained with no tempering treatment.

An improvement in the elastic limit is also accomplished by scragging springs. This is another form of cold work obtained by the common commercial practice of deliberately overloading the spring so as to produce a permanent set or deflection. On chrome-vanadium coil spring Manteuffel[illegible] showed that in some cases this scragging lowered the fatigue strength somewhat and in others a slight increase was obtained. Prever and Locati[illegible] also found that prestressing gave a slight increase on helical springs made from drawn wire. On leaf springs subjected to bending loads Becker and Phillips[illegible] obtained a greater improvement, namely from 56,000 lb. per sq. in. to 73,000 lb. per sq. in. or 32 per cent.

Parts of high hardness having sharp corners are sometimes given a low temperature stress relieving treatment after shot peening to prevent the corners breaking off.

Ed. Note:—Next week the author concludes this appraisal by examining the control of shot peening, peening steels and light alloys, shot size and time.

peening of gears, and gun parts, crankshafts, and studs and bolts, and liquid blast.

BIBLIOGRAPHY

[1] F. P. Zimmerli, "Shot Blasting and Its Effects on Fatigue Life," in book, "Surface Treatment of Metals," Amer. Society Metals, 1944, pp. 261-278. Also "How Shot Blasting Increases Fatigue Life," Machine Design, November, 1940, p. 62.

[2] W. L. H. Steele in discussion of paper in reference 1.

[3] J. G. Gagnon in discussion of paper in reference 1.

[4] Steel, December, 1943, pp. 29-30.

[5] J. O. Almen, "Improving Fatigue Strength of Machine Parts," The Iron Age, June 10, 1943, pp. 65-69, 125-131. Also "Peened Surfaces Improve Endurance of Machine Parts," and related subjects in Metal Progress, February, 1943, pp. 209-215, 270; May, 1943, pp. 737-740; August, 1943, pp. 254-261; September, 1943, pp. 435-440. Also "Shot Blasting to Increase Fatigue Resistance," S.A.E. Journal (Transactions), vol. 51, No. 7, July, 1943, pp. 249-268.

[6] O. Foppl, "Compression of the Surface of Steel Machine Parts," Stahl und Eisen, vol. 49, 1929.

[7] O. Foppl, "Surface Compression as a means of Increasing the Fatigue Strength of Springs Used in Motor Vehicles," Automobiltechnische Zeit., vol. 45, No. 12, June 25, 1942, pp. 321-325.

[8] S. G. Von Heydekampf, "Cold Rolling Raises Fatigue or Endurance Limit," The Iron Age, vol. 126, Sept. 18, 1930, p. 775. Also see F. F. Johnson and T. W. Lippert, "Axle Fatigue Inhibited by Trumtraining," The Iron Age, March 29, 1934.

[9] U. S. Patents Nos. 1,946,340, Feb. 6, 1934, and 1,947,927, Feb. 20, 1934, by Paul Otto F. Vorwerk assigned to Rochling Steel Works.

[10] H. Wiegand "Effect of Surface Treatment on Fatigue Strength," BMW Flugmotorenbau, 1940.

[11] E. G. Herbert, "Work Hardening of Steel by Abrasion," Journal, Iron and Steel Inst., 1927, No. 11, pp. 265-282.

[12] E. E. Weibel, "The Correlations of Spring-Wire Bending and Torsion Fatigue Tests," Trans. A.S.M.E., vol. 57, November, 1935, p. 501.

[13] R. E. Peterson and A. M. Wahl, "Fatigue of Shafts at Fitted Members," Journal of App. Mech., Trans., A.S.M.E., vol. 57, 1935, p. A-1.

[14] O. J. Horger, "Effect of Surface Rolling on the Fatigue Strength of Steel," Journal of Applied Mechanics, Trans. A.S.M.E., vol. 57, 1935, p. A-128.

[15] O. J. Horger and J. Maulbetsch, "Increasing the Fatigue Strength of Press-Fitted Axle Assemblies by Surface Rolling," Journal of Applied Mechanics, Trans. A.S.M.E., vol. 58, September, 1936, p. A-91.

[16] J. H. Frye and G. L. Kehl, "Fatigue Resistance of Steels as Affected by Some Cleaning Methods," Transactions, Am. Soc. Metals, vol. 26, 1938, p. 192.

[17] O. Foppl, "Surface Pressing with a View Towards Increasing the Endurance with the Help of the Steel Ball Blast," Mitt. D. Wöhler Inst., Braunschweig, No. 36, 1939, pp. 44-48.

[18] J. M. Lessells and W. M. Murray, "The Effect of Shot Blasting and Its Bearing on Fatigue," Proc. Am. Soc.

Testing Mats., vol. 41, 1941, pp. 659-681.

[19] R. Z. Manteuffel, "Fatigue Endurance of Power Vehicle Springs and Possibilities of Influencing Same," Kraftfahrforschung, No. 49, 1941, pp. 1-51.

[20] H. Lüpfert, "Material Investigation Problems in the Art of Fine Mechanics," Z.V.D.I., vol. 87, No. 31/32, Aug. 7, 1943, pp. 481-488.

[21] H. F. Moore, "A Study of Residual Stresses and Size Effect and A Study of the Effect of Repeated Stresses on Residual Stresses Due to Shot Peening of Two Steels," Soc. for Exp. Stress Analysis, vol. 2, No. 1, 1944, pp. 170-177.

[22] O. J. Horger and H. R. Neifert, "Improving Fatigue Resistance by Shot Peening," Soc. for Exp. Stress Analysis, vol. 2, No. 1, 1944, pp. 178-190.

[23] O. J. Horger and H. R. Neifert, "Shot Peening to Improve Fatigue Resistance," Soc. for Exp. Stress Analysis, vol. 2, No. 2, 1944.

[24] H. F. Moore, "Shot Peening and the Fatigue of Metals," in two separate publications of American Foundry Equipment Co., Mishawaka, Ind., 1944.

[25] "Mechanical Springs, Their Engineering and Design," William D. Gibson Co., Chicago, p. 34.

[26] F. Bollenrath & W. Bungardt, "Influence of Surface Decarburization and Pre-Heat Treatment Upon the Fatigue and Time Strength of Steel Guy Wires," Arch. f. d. Eisenhüttenwesen, vol. 12, No. 4, October, 1938, pp. 213-18.

[27] E. T. Gill and R. Goodacre, "Some Aspects of the Fatigue Properties of Patented Steel Wire," J. Iron Steel Inst., London, vol. 130, 1934, pp. 293-323.

[28] R. G. C. Batson and V. Bradley, "Bending Fatigue Resistance of Flat Springs With As-Rolled Surface," Proc. Instn. Mech. Engrs., London, vol. 120, 1931, pp. 301-32; also Engineering, vol. 131, 1931, p. 405.

[29] G. A. Hankins and M. L. Becker "The Effect of Surface Conditions Produced by Heat Treatment on the Fatigue Resistance of Spring Steels," J. Iron Steel Inst., London, vol. 124, 1931, pp. 387-460.

[30] G. A. Hankins and H. R. Mills, "Resistance of Spring Steels to Repeated Impact Stresses," J. Iron Steel Inst., London, vol. 131, 1935, pp. 165-80.

[31] G. A. Hankins, M. L. Becker and H. R. Mills, "Further Experiments on the Effect of Surface Conditions on the Fatigue Resistance of Steels," J. Iron Steel Inst., London, vol. 133, 1936, pp. 399-449.

[32] Eaton Mfg. Co., S.A.E. Journal, February, 1942, p. 129.

[33] U. S. Patents Nos. 2,234,850, March 11, 1940; 2,249,678, July 15, 1941; 2,252,823, Aug. 19, 1941; assigned to Eaton Mfg. Co. by William H. Wallace.

[34] K. Lippacher, "Increase in Torsional Fatigue Resistance of Splined Torsional Bar Springs by Super Rolling," Werkstattechnik and Werkleiter, vol. 34, No. 22, Nov. 15, 1940, pp. 369-371. Also see O. Foppl, Die Werkzeug machine.

[35] L. E. Simon, "Improvement of Parts on Motive Power," A.S.M. Symposium on Shot Peening, October, 1944.

[36] V. Prover and L. Locati, "The Phenomenon of Spring Failure," Metallurgy Ital., vol. 27, 1935, pp. 188-204 and 256/74.

[37] M. L. Becker and C. E. Phillips, "Internal Stresses and Their Effect on the Fatigue Resistance of Spring Steels," J. Iron Steel Inst., London, vol. 133, 1936, pp. 427-53.