

[54] **SHOT PEENING**

158, 162, 168, 227, 255, 256, 257

[75] Inventors: **Phillip M. Winter**, White Bear Lake;
Gary A. Gardner, Saint Paul, both
of Minn.

[56]

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[73] Assignee: **Minnesota Mining and
Manufacturing Company**, St. Paul,
Minn.

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Related U.S. Application Data

[62] Division of Ser. No. 59,850, June 25, 1970, Pat. No. 3,778,241, which is a division of Ser. No. 746,366, July 22, 1968, Pat. No. 3,638,464.

Primary Examiner—William J. Van Balen

Assistant Examiner—Alan T. McDonald

Attorney, Agent, or Firm—Alexander, Sell, Steldt and DeLaHunt

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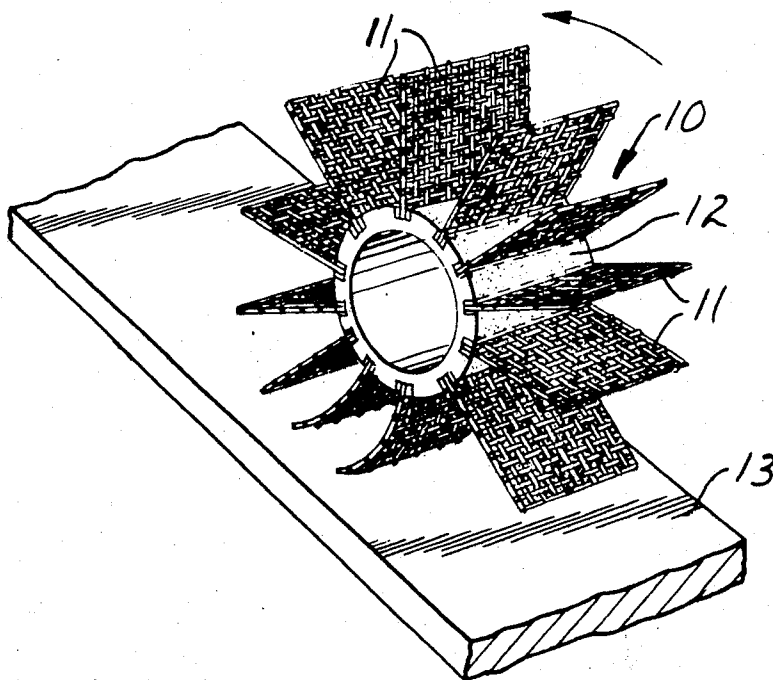
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[57]

ABSTRACT

A rotary wheel, in which spheroidal peening particles are affixed to radially extending circumferentially spaced flaps of fibrous sheet material, is used to impart compressive stress to, or aid in shaping, metallic substrates.

3 Claims, 5 Drawing Figures



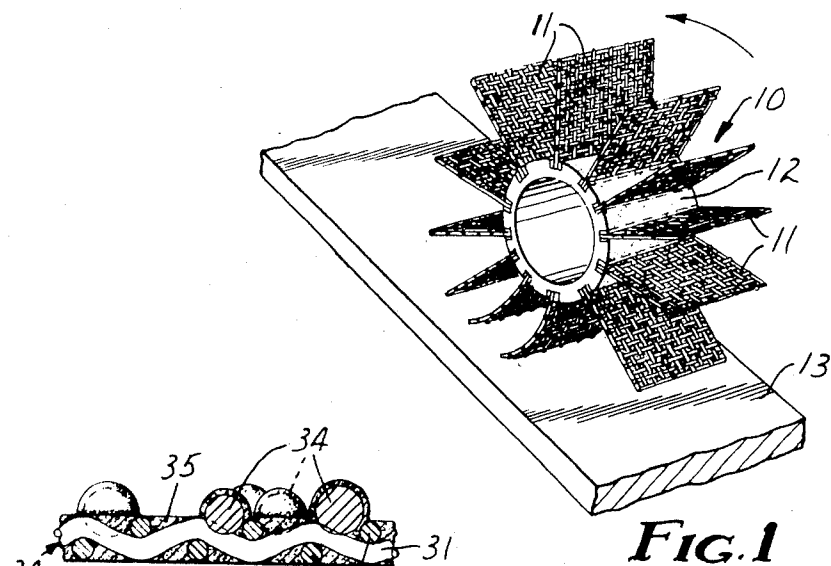
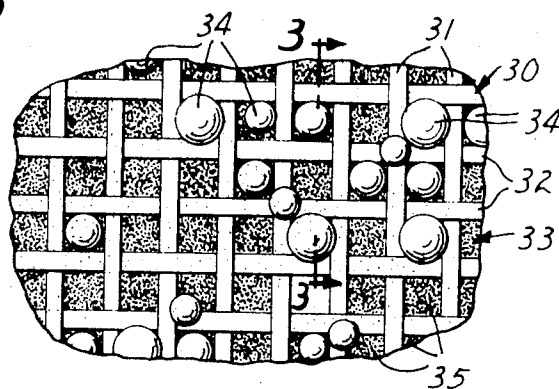
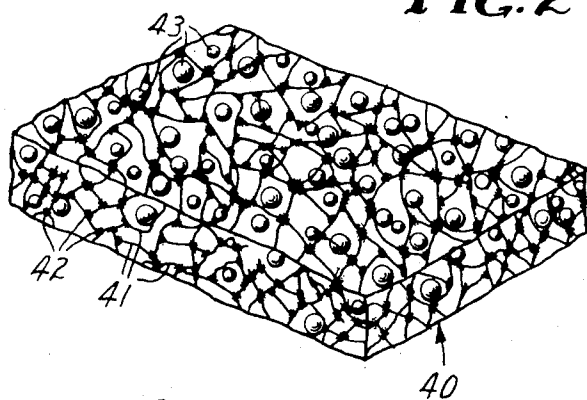
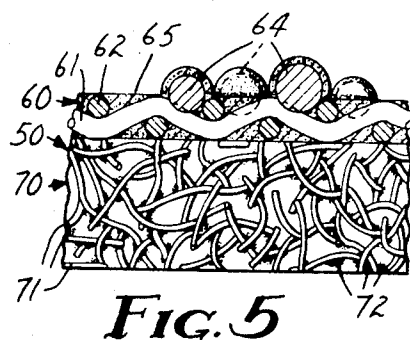


FIG. 3



SHOT PEENING

This is a division of application Ser. No. 59,850 filed June 25, 1970, now U.S. Pat. No. 3,778,241, which application is a division of Ser. No. 746,366 filed July 22, 1968, now U.S. Pat. No. 3,638,464.

BACKGROUND OF THE INVENTION

It has long been customary to shot peen to increase fatigue strength, to relieve tensile stresses that contribute to stress-corrosion cracking, to form and straighten metal parts, etc. A detailed description of this process and the materials used therein is found in the ASM Committee "Metals Handbook," Volume 2, 8th Division, 1964, pages 398-405, and incorporated herein by reference. Prior art shot peening processes are also described in numerous patents, e.g., U.S. Pat. Nos. 2,542,955 and 2,982,007. In conventional shot peening, spheroidal particles of cast steel, cast iron, glass, etc. are blown or mechanically impelled in a high velocity stream against the surface to be treated. The individual shot particles produce shallow, rounded overlapping dimples in the surface, stretching it radially from each point of impact and causing cold working and plastic flow. The resultant compressive stress tends to counteract tensile stresses imparted to the substrate by the preceding rolling, bending, abrading, and similar processes.

The degree of peening, which is generally expressed as "peening intensity," is a function of the weight, size, hardness and velocity of the peening particles, exposure time, type of substrate, angle of impingement, and various other factors. It is conventional to express peening intensity in terms of Almen arc height, according to SAE Test J442, described in some detail in Military Specification MIL-S-13165B. In this test, a thin flat piece of steel is clamped to a solid block and exposed to a blast of shot, which, as previously indicated, tends to stretch the surface, so that the strip will be curved when removed from the block. Test strips are SAE 1070 cold rolled spring steel uniformly hardened and tempered to a hardness of 44-50 Rockwell C, 3 ± 0.015 inch long and 0.745-0.750 inch wide. The strips are one of three thicknesses: A, 0.051 inch ± 0.001 inch; C, 0.0938 inch ± 0.001 inch; and N, 0.031 inch ± 0.001 inch. The height of arc of the resultant chord in inches is referred to as the Almen arc height, greater heights indicating greater peening intensity for a given test strip thickness.

Effective though it is for many purposes, conventional shot peening suffers from disadvantages which drastically limit its usefulness. For example, large and expensive equipment is required for rapidly impelling shot toward a surface and collecting, screening and recirculating the shot particles. Equipment of this type is not readily portable, and hence is suitable only for those metal pieces or parts which can be brought to the shot peen station. It is virtually impossible to shot peen a part while it still remains attached to another piece of equipment.

Despite the foregoing drawbacks to the shot peening process, there has previously been no effective alternative. It is to this unsolved need that the present invention is directed.

SUMMARY OF THE INVENTION

The present invention provides a novel means and method for carrying out shot peening procedures.

Peening intensities achieved are equal to those obtained by any conventional shot peening operation, but the customary elaborate and expensive machinery is not required. There is no need, for example, to use special impelling, screening, collecting, or recycling equipment. The novel device, which is portable, simple, and convenient to operate, can be driven by equipment no more complicated than a conventional electric motor or a flexible shaft connected to such a motor. Large parts can be peened, even while they remain attached to a still larger piece of equipment, permitting the in-service stress-reduction maintenance of aircraft, automobile springs, etc.

The device of this invention comprises an annulus of radially extending peripherally separated flaps which are united at their radially inner ends to a rigid core. Each such flap is a flexible, tough, tear-resistant fibrous support to which shot peening particles are bonded at spaced portions by a strong, tough organic adhesive. In use, the annulus is mounted on a shaft and rotated rapidly while the periphery is forced against the substrate to be peened. A portion of the flat face of each flap strikes the substrate in turn, thereby causing the peening particles to perform their normal peening function, but preventing their normal uncontrolled scattering.

In practice, it is advisable first to determine the approximate peen intensity desired, taking into account the type of substrate involved, the particular metal alloy, geometry of the part and stress condition expected in use. Most aircraft and automotive manufacturers have either developed their own shot peening specifications or are able to consult pertinent military specifications. Next, it is recommended that an Almen test specimen be adhered to the actual surface to be peened (using double-coated tape or other suitable means) so that peening intensity can be monitored. The shot peen wheel and operating speed are then chosen so as to achieve the approximate intensity desired.

Typical applications for the products of this invention include both initial and repair stress conditioning of metal parts to enhance fatigue strength and resistance to stress corrosion cracking. Among the parts which can be treated are torsion bar springs, leaf springs, oil well drill pipes, shafts and axles, piston pins, crankshafts, landing gear assemblies, connecting rods, wing strut supports, etc. Decarburizing, heavy scale removal, stress conditioning before chrome plating and surface finishing to produce attractive matter luster are additional applications. Wheels of the invention are also well suited for peen forming or peen straightening metallic parts. An operator can accurately bend or bow the shape of a metal component, for example, a helicopter rotor blade, to the desired configuration by applying a shot peen wheel to the surface. Since no enclosure is necessary, the part remains in full view at all times. Another outstanding advantage of the present invention is the ease of varying the type or size of peening particles, which is accomplished simply by changing wheels, whereas conventional shot peen systems require complete cleanout and recharge of the shot chamber.

It should be pointed out that "flap wheels" are broadly old, as is evidenced by patents dating well back into the nineteenth century. Although such wheels have previously been used for a wide variety of buffing, cleaning, polishing, and abrading operations, it is believed that there has never heretofore existed a flap

wheel construction suitable for use in shot peening operations.

BRIEF DESCRIPTION OF DRAWING

Understanding of the invention will be facilitated by reference to the accompanying drawing, in which:

FIG. 1 is a view of a self-contained rotary peening wheel made in accordance with the invention;

FIG. 2 is a segment of a flap of the type used in preparing the wheel of FIG. 1;

FIG. 3 is a cross-section of the article of FIG. 2, segment of a woven flap which may be used in preparing the wheel of FIG. 1;

FIG. 4 is a segment of a nonwoven flap which may be used in preparing wheels similar to that shown in FIG. 1; and

FIG. 5 is a segment of a composite woven-nonwoven flap which may be used in preparing wheels similar to that shown in FIG. 1.

DESCRIPTION OF PRESENTLY PREFERRED EMBODIMENTS

Although the principles of this invention can be embodied in such simple devices as a split rotary shaft which grips a single elongated shot peening strip, it is generally preferred to employ a structure with a greater number of flaps. As is particularly shown in FIG. 1, wheel 10 comprises a plurality of flaps 11, the radially inner ends of which are adhered to core 12, wheel 10 being driven in the direction of the arrow while being forced against substrate 13. The spacing between circumferentially adjacent flaps 11 should be great enough to permit a substantial portion of the radially outer portion of each flap 11 to strike substrate 13. The rotary device is so positioned that the spacing between core 12 and substrate 13 is significantly less than the radius of flap 11, thereby enhancing the peening action. As the specific examples which follow will show in detail, flaps 11 may be formed from fibrous sheet material of various types.

FIGS. 2 and 3 illustrate a section of sheet material, suitable for forming flaps, formed from an open mesh fabric 30 woven from warp yarns 31 and weft yarns 32, the yarns being spaced so as to define therebetween open meshes 33. Bonded to yarns 31 and 32 and generally resting in meshes 33 are peening particles 34, adhesive 35 serving to bond particles 34 in place and also to unify fabric 30.

FIG. 4 illustrates section of sheet material which comprises a nonwoven lofty three-dimensional fibrous structure 40, individual fibers 41 being bonded to each other at points where they contact by means of adhesive 42. Also bonded to spaced portions of fibers 41 are peening particles 43. Abrasive products superficially similar to this construction, but lacking the peening ability of the product shown in FIG. 2, are described in U.S. Pat. No. 2,958,593.

When the individual flaps used in making the device of this invention are formed from lofty nonwoven fibrous sheet material, the diameter of the fibers, or filament segments, influences the performance of the finished product; fibers having a diameter of at least 40 microns, and preferably in the range of 40-200 microns are preferred. All other factors being equal, when 25-denier nylon fibers (55-microns diameter) are used, their ready mobility imparts a greater peening intensity than when 250-denier (175-microns diameter) fibers

are used. On the other hand, coarse denier fibers are strong, wear resistant, and tend to provide better anchorage, especially for coarser peening particles. Nylon fibers of 200 denier (160-microns diameter) have been found especially suitable for most purposes. To assure formation of lofty open sheet material, the fibers should be crimped.

FIG. 5 shows in cross-section a composite product 50 formed from open mesh woven fabric 60 and lofty open nonwoven mat 70, and suitable for making peening flaps. Fabric 60 is woven from spaced warp yarns 61 and spaced weft yarns 62, defining open meshes. Bonded to yarns 61 and 62 and generally resting in the meshes are peening particles 64, adhesive 65 serving to bond particles 64 in place and also to unify fabric 60. Bonded to the back surface of woven fabric 60 is lofty open nonwoven fibrous structure 70, made up of individual fibers 71 adhesively bonded to each other at points of contact by adhesive 72. A wheel made with flaps of such composite material is rotated in a direction such that woven fabric 60, bearing peening particles 64, contacts the substrate first.

Each of the three sheet materials illustrated has advantages for use in the practice of this invention. For example, products of the type shown in FIGS. 2 and 3 are inexpensive and easy to manufacture, long wearing, and impart relatively "pure" peening action. Products of the type shown in FIG. 4 are conformable and better able to extend into and uniformlypeen concavities, recesses and depressions. Composite products of the type shown in FIG. 5 have outstanding fatigue resistance and the peening intensity which they generate approximates a linear (and hence fairly predictable function of rotative speed.

Regardless of the specific construction of flap-forming sheet material, the peening particles are substantially spheroidal relatively smooth impact-resistant inorganic particles having an average diameter in the range of 0.1-2.5 mm. Because peening particles cover a wide spectrum of specific gravities, it has been found that the quantity of particles present can best be expressed in terms of cubic centimeters per square meter of backing, effective amounts ranging between 25-1,000 cc/m². Products of the type shown in FIGS. 1-3 and 5 function effectively with relatively small amounts of peening particles, e.g., as low as 25 cc/m² of usable flap area, 150-500 cc/cm² performing especially well. Products of the type shown in FIG. 4 function effectively with a relatively large range in the amount of peening particles; 100-1,000 cc/m² can be used, 400-700 cc/m² being preferred. Individual peening particles should be spaced sufficiently far apart so that their ability to make distinct and separate impressions on the workpiece is not impaired. In order to insure that the peening particles are retained on the flaps, each such particle should have at least somewhat more than half of its diameter surrounded by bonding adhesive.

Peening particles can be formed from any of the materials used in conventional shot peening operations, e.g., cast steel, cast iron, glass beads, and the like, or such hard and dense materials as tungsten carbide. Generally speaking, hardness of the peening particles is not especially critical, provided that it is harder than the substrate. Relatively large particles (e.g., 2.5 mm) are not only difficult to anchor firmly to flaps but also make it difficult to obtain uniform peening coverage.

On the other hand, relatively small particles (e.g., 0.1 mm or less) are easy to anchor, afford uniform peening coverage and are quite effective in imparting residual compressive surface stress, albeit to only a shallow depth. To reduce breakage, friable peening particles should be avoided.

The adhesive which bonds the peening particles to fibers of the individual flaps should, of course, be both fiber- and peening particle-adherent. Additionally, it should have a tensile strength of at least about 150 kg/cm² and an ultimate elongation at break of at least about 100%. Suitable adhesives include various blends of phenolic resin and butadiene:acrylonitrile copolymer, and particularly the reaction product of a polytetrahydrofuran prepolymer and a chain extending agent. Suitable adhesives of the latter type include the reaction product of isocyanate-terminated polytetrahydrofuran prepolymer and methylene dianiline, and the reaction product of an amine-terminated polytetrahydrofuran prepolymer and a bisphenol A-type epoxy resin.

Further understanding of the invention will be gained from the following specific examples, in which all parts are by weight unless otherwise noted.

EXAMPLE 1

This example describes the manufacture of a shot peening flap wheel in which the individual flaps are formed from a nonwoven fibrous web.

An adhesive was prepared by adding to a tin-plated container 40.0 parts of ethylene glycol monoethylether acetate solvent and 4.02 parts of p,p' methylene dianiline (MDA), a high speed propeller mixer being used to mix the two components until the MDA had dissolved. To the solution was then added 31 parts of a 100% solids urethane elastomer with blocked isocyanate curing sites, formed by the reaction of polyether glycol with an excess of aromatic diisocyanate and a ketoxime, having a molecular weight of less than 200 (commercially available from E. I. duPont de Nemours & Company under the trade designation "Adiprene" BL-16). Also added at the same time were 12½ parts of a finely divided talc filler and 1.45 parts of glycidoxypentyl trimethoxy silane (commercially available from Dow Corning Corporation under the trade designation "Silane Z6040"). Although not absolutely necessary, it has been found that the silane improves adhesion to both fibers and peening particles, thereby improving wear life of the finished wheel product. All of the ingredients were then mixed for an hour, the viscosity of the resulting mixture being approximately 100 cps. at 24°C.

A lofty open nonwoven web was formed, using a "Rando-Webber" machine, from 200-denier crimp-set 1½-inch staple nylon fibers, the web having a thickness of approximately ½ inch and a weight of approximately 31 mgm/cm². The web was then pre-bonded by passing it through a pair of 70-durometer rubber squeeze rolls, the lower of which was immersed in a bath of adhesive described in the preceding paragraph, applying a coating weight (solids basis) of approximately 13 mgm/cm². The web was passed through a 140°-160°C. oven so that the adhesive was tack free, even while warm, the resulting web thickness being on the order of one centimeter.

An adhesive formulation identical to that described in the second paragraph of this example was prepared,

except that the amount of ethylene glycol monoethyl ether acetate was reduced to 20 parts, resulting in a viscosity of 600 cps. at 24°C. The pre-bonded web was then passed through squeeze rolls as in the preceding paragraph, so as to apply the adhesive in an amount equal to approximately 70 mgm/cm² (solids basis). Size No. 460 cast iron shot peening particles (nominal diameter 0.0460 inch, or 1.17 mm), having a Rockwell C hardness of 60-65, were blown into each face of the adhesive-coated web, thereby assuring uniform penetration throughout, a total of approximately 450 mgm/cm² (about 600 cc/m²) being applied. The "make" resin was then cured in the same manner as the prebond. A light "sandsize" coat (about 30 mgm/cm²) of the same adhesive was applied with a hand controlled paint spray gun and the adhesive cured at approximately 65°C. for 15 minutes and approximately 140°C. for 2 hours. The ultimate thickness of the finished product remained approximately one centimeter.

From the cured nonwoven fibrous sheet material referred to in the preceding paragraph, 38 1½-inch × 2½-inch flaps were cut and stacked in a 1½-inch wide steel channel at the bottom of which had been placed a strip of normally tacky and pressure-sensitive adhesive filament tape, adhesive side up. A phenolic resin-impregnated spiral-wound jute core having an inner diameter of 3 inches and an outer diameter of 3½ inches was positioned on top of the center flaps, and the strip of tape, to which one 1½-inch end of each flap was now firmly adhered, used to form the flaps into an annulus about the core. The flaps uniformly peripherally spaced in radial alignment about the core and a second strip of filament tape was then wrapped around the periphery of the resultant annulus and used to tighten the flaps. The core was then removed and painted with an epoxy-polyamide resin (equal parts of "Epon" 828, commercially available from Shell Chemical Company and "Versamid" 125, commercially available from General Mills, together with 2% blown silica filler, commercially available from Godfrey L. Cabot Corporation under the trade designation "Cab-O-Sil M5"). The radially inner ends of the flaps were then painted with the same resin, the core re-inserted in the annulus, the resin cured at 65°C. for ½ hour and 120°C. for ½ hour, and the tape then removed. Two other wheels, identical except for incorporation of a lesser number of flaps, were prepared in the same manner.

Each of the wheels described in the preceding paragraph was mounted on a shaft, driven at about 3,500 rpm (3,750 rpm, no load) and urged against an Almen A test strip with a force of 13 lbs., arc height peening intensity being measured periodically. Results are tabulated below:

No. of flaps in wheel	Arc height peening intensity, mils, at times noted					
	10 sec.	20 sec.	30 sec.	40 sec.	50 sec.	60 sec.
38	5	7	7	8	9	9
19	9	14	16	19	21	22
9	16	21	26	29	33	37

It appears that the peening intensity attained after any given time at constant speed and pressure is an inverse function of the number of flaps in the wheel. It further appears that the more densely packed the wheel, the less vigorous, but the more closely controllable, the

peening intensity which can be attained. It is presently felt that flap separation of at least 10° or ½ inch at the tip, whichever is greater, is desirable.

Another wheel similar to those described above, was formed using 13 flaps and tested at several speeds for the peening intensity imparted to an Almen A test strip after 60 seconds. Results are tabulated below:

Speed, rpm	Arc height peening intensity, mils
1200	0.5
1600	1
2000	2
2300	3
2700	5
3000	7
3400	10

The wear life properties of wheels of the type described in this Example 1 are dependent upon operating condition, geometry of substrate, number of flaps and size of shot. A flap wheel containing 38 flaps on a 3-inch core, 8 inch total wheel diameter, cast iron shot size 280, can be operated on relatively flat, smooth surfaces for about 40 hours at essentially constant peening effectiveness before the flaps are worn down. If size 550 shot is employed, wheel life is reduced to about 5 hours.

Wheels of this type function well when mounted on an electric grinding tool driven at a speed which will impart a velocity of 500 to 8,000 surface feet per minute to the shot particles at the periphery of the wheel. The motor should have sufficient power to maintain a nearly constant velocity under load. The hand held tool is applied to the surface in short back and forth strokes (e.g., on the order of 4 inches), so as to cover the entire surface evenly and uniformly. Ultimate control of applied stress uniformity is obtained if automated sheet metal grinding or finishing equipment is employed; however very acceptable results are readily achieved by a hand operation. Visual inspection of the pattern of peen impressions provides an effective means for estimating uniformity. Although peening intensity is not seriously affected by variations in applied load pressure at constant speeds, it continues to increase with time of exposure until the saturation intensity level is reached.

An extremely simple but particularly versatile and effective peening tool can be made with a single 1 inch × 1¼ inch strip of shot peening material of the type described in Example 1 by gripping the strip, midway between its ends, in a bifurcate mandrel. This tool should be mounted on a high speed electric or air motor grinder chosen to achieve about 6,000–10,000 rpm under load. Not only is this type of tool readily capable of imparting high peen intensities, but it can also be constructed in very small dimensions to facilitate the peening of inner surfaces of holes, pipes, recesses and the like. Such simple devices are also extremely useful for rapidly evaluating a variety of peening web constructions. The table set forth below shows the peening intensities attained in one minute at 10,000 rpm on Almen A test strips, utilizing a variety of peening particle sizes and types:

Nominal particle diameter, mils	Arc height peening intensity, mils, for type of peening particle noted				
	Cast iron	Tungsten carbide	Copper	Stainless steel	Glass bead
19	—	—	—	—	1
23	—	—	—	3	—
33	6	—	—	—	—
45	9	17	—	9	—
55	12	—	—	—	—
60	—	—	0.5	—	—

EXAMPLE 2

This example describes the manufacture of a shot peening flap wheel from peening material similar to that in Example 1 but in which the flaps are formed in a different manner.

Nonwoven lofty web material having peening particles bonded throughout was prepared as in Example 1, using Size No. 330 cast iron shot (nominal diameter, 0.331 inch, or 0.84 mm) and omitting the sandsize adhesive. Two 5 inch diameter discs, each having a 1¼ inch center hole, were then died from the web. From the periphery of one disc, 14 equally spaced radially extending notches, about ½ inch wide at the periphery and 1 inch deep along the radius, were then cut. The resultant product had the general appearance of a spur gear, with 14 "teeth," each about ½ inch wide, 1 inch long and ⅜ inch thick, and was analogous to the flap wheels made in Example 1.

Each of the two discs described in the preceding paragraph, one having teeth and the other not, was then mounted between 3-inch side plates, installed on a flexible shaft machine, and applied to a series of Almen A test strips for 60 seconds with a force of 7 lbs. at a range of speeds. Results are tabulated below:

Speed, rpm	Arc height peening intensity, mils		Temperature of Almen A test strip after peening, °F.	
	Continuous wheel	Toothed wheel	Continuous wheel	Toothed wheel
1100		0.3	100	100
1500	0	0.9	105	100
1830	0.3	2.6	110	100
2150	1.2	3.1	135	100
2450	1.9	4.5	160	110
2775	3.0	7.0	150	110
3050	4.8	8.2	170	110
3350	5.9	10.3	205	110

It is noted that peening intensity is directly related to the speed at which peening particles strike the test strip. The foregoing table also shows that a toothed wheel peens more effectively and at a lower temperature than a continuous wheel, in which the binder tended to smear on the test strip at high speeds. Continued use at high speeds caused some tooth loss, indicating that this method of flap formation is less desirable than that described in Example 1. It is considered desirable, however, for the fibers of the web to wear away when peening particles are lost during use, permitting fresh particles to assume the peening role.

EXAMPLE 3

This example describes the manufacture of a shot peening flap wheel in which the backing is a square weave open mesh cloth.

To a tin-plated steel container was added 13 parts of methyl ethyl ketone and 13 parts of MDA, as described

in the preceding example, a propeller mixer being used to dissolve the MDA in the solvent. Next 100 parts of "Adiprene ML-16 inches and 4.7 parts of "Silane Z6040" (see previous example) were added and all components mixed for 30 minutes, the resulting viscosity being 2,000 cps. at 24°C.

A square weave greige cloth nylon scrim formed of sixteen 840-denier threads (140 filaments per thread) per inch in both the warp and weft directions, having a 250 lb/in. (approximately 45 kg/cm) "grab" tensile strength in both length and cross directions, sized with a vinyl resin in an amount equal to about ¼ the fiber weight, and weighing approximately 16 mgm/cm², was obtained. To one face of the cloth just described was applied the resin described in the preceding paragraph, the coating weight being on the order of 17 mgm/cm² (dry basis). Size No. 390 (nominal diameter 39.4 mils, or about 1 mm) cast iron shot was then sprinkled on the adhesive coated face of the cloth to provide a random coating of approximately 0.14 gm/cm², an amount equal to approximately 180 cc/m². The resin was then cured for 15 minutes at approximately 65°C. and for 30 minutes at approximately 140°C., after which a "sand-size" coat of the same resin was applied in approximately the same amount as the previous coat. The resin was then cured for 15 minutes at approximately 65°C. and for 2 hours at approximately 140°C. The cast iron peening particles tended to collect in mesh openings, where they were nestled in a resin socket.

The sheet material described in the preceding paragraph was then cut into individual 1½-inch × 1¾-inch flaps. In the peripheral exterior of a core of the type described in Example 1, 12 equally spaced slots 3/32-inch wide and 3/32-inch deep were cut so as to extend parallel to the axis of the core. Each such slot was then filled with an epoxy-polyamide resin of the type described in Example 1 and the core placed on its side on a silicone-coated release paper. Into each slot was then inserted a flap, the surface of the flap bearing the peening particles facing the same direction in each case. The resin was then cured at room temperature (24°C.) for 12 hours.

In general, the desiderata relating to the type of power tool to employ, the effects of speed, size of shot, type of shot, dwell time, etc., which were discussed for the construction described in Example 1 also apply generally to the construction of Example 3. The notable differences are that the wheel of Example 3 is capable of generating higher peen intensities and exhibits a lower rate of wheel wear compared with the wheel of Example 1, all other conditions being equal. For example, roughly 30% increase in peen intensity and four fold decrease in wheel wear rate are observed for the wheel of Example 3 as compared with Example 1. It should be noted however, that the attractive feature of lower wheel wear for the wheel of Example 3 is somewhat offset by the high peen intensities obtained in short times, which may cause difficulty in controlling and maintaining uniformity.

EXAMPLE 4

This example describes the manufacture of a shot peening flap wheel in which the flaps are made from a laminate of woven and nonwoven materials.

A nonwoven lofty fibrous web about 3 mm thick and weighing 8.4 mgm/cm² was formed on a "Rando-Webber" machine from 15-denier nylon fibers and roll

coated with approximately 3.4 mgm/cm² (solids basis) of a composition formed by blending the following:

Saturated hydroxyl-terminated slightly branched polyester resin (commercially available from Mobay Chemical Company under the trade designation "Multron" R-68)	100.0
75% solids solution of the reaction product of one mol of trimethylolpropane and 3 mols of toluene diisocyanate in ethyl acetate (commercially available from Mobay Chemical Company under the trade designation "Mondur" CB-75)	83.4
Hexanetriol	5.04
Ethylene glycol monoethyl ether acetate	150

The composition was then cured by heating 15 minutes at 65°C. and 45 minutes at 140°C.

The woven peening sheet material described in Example 3 was coated on the back (side opposite the peening particles) with a thin layer of the make resin described in Example 3, firmly forced against one surface of the nonwoven web described in the preceding paragraph, and the resin cured by heating as in Example 3. From the cured laminate 12 1½ × 2½ inch flaps were formed and adhered to the periphery of a 1-3/8 O.D. core similar in construction to that used in Example 1, all flaps being aligned to face in the same direction. The stiffness and resilience of each flap were significantly greater than for the flaps of Example 3, facilitating both handling and wheel formation. The flaps extended in substantially straight radial array, even after extended use, rather than assuming a curved configuration.

The wheel of this Example 4 could be used for the same purposes as the wheel of Example 3, but permitted a more precise control of the peening process. When the wheel was examined after extended use, it was found that the individual flaps remained in substantially straight radial array, rather than assuming a curved configuration. It was also found that the flaps did not fatigue at their point of attachment to the core. The nonwoven lamina provides sufficient strength that a wide variety of open mesh scrim cloths may be used to achieve a desired particle spacing, even though such cloths may not be especially strong.

Wheels of the type described in this Example 4 have proved highly effective in the contour adjustment of helicopter rotor blades. Such blades, which are typically about 1½ feet wide and 22 feet long, are made from a relatively thin aluminum skin laminated over a honeycomb core to a precisely contoured airfoil shape. Each blade may cost several thousand dollars, yet it will be scrapped for any deviation from a 0.015 inch or less contour range at several check points. The wheel of this example can be applied to the appropriate side of an out-of-tolerance blade to stretch the skin and thus adjust contour as much as ± 0.050 inch.

In some operations, it is desirable to utilize a process in which shot peening is combined with a certain amount of abrasive cleaning, e.g., in the removal of scale from hot rolled steel. The inclusion of at least a minor amount of abrasive particles in structures of the type disclosed hereinabove permits a combination ac-

tion in which the scale is shocked loose by the peening particles and whisked away by the abrasive particles, the peening particles insuring that the ultimate stress imparted to the work surface is compressive, rather than tensile, and hence that the peak strength of the product remains improved. Products of this type can also be made by alternating peening particle-coated flaps and abrasive particle-coated flaps, the specific ratio of one type of flap to the other being governed by the result which it is sought to achieve.

As has previously been indicated, shot peening improves the fatigue resistance of metals. A commonly used device for evaluating fatigue resistance is the R. R. Moore High Speed Fatigue Testing Machine, a rotating beam type machine in which a notched cylindrical metal test specimen functions as a simple beam symmetrically loaded at two points. When the specimen is at rest, fibers above its neutral axis are in compression and those below this axis are in tension. As the specimen rotates, the stresses in these fibers are gradually reversed until at the end of one-half revolution those originally in compression are in tension. Thus, during each complete revolution the test specimen passes through a complete cycle of flexural stress; the nominal operating speed produces 10,000 cycles of stress per minute at a bending moment which can be adjusted to a value which will yield the desired extreme fiber stress for the test specimen. Detailed information is available from The Warner & Swasey Co. or Baldwin-Lima Hamilton Corporation.

To determine the effectiveness of various flap wheels made with Size 330 cast iron peening particles in improving fatigue resistance, a series of tests were run on the R. R. Moore Machine with 7075-T6. Aluminum test specimens each having a 0.55 inch diameter circular cross section and grooved with a 0.125 inch radius notch, treating them for one minute at a speed yielding a saturation peening intensity of Almen A 0.008 inch. Results are tabulated below:

Type flap	Fatigue life, cycles $\times 10^4$, at extreme fiber stress (psi $\times 10^3$) indicated			
	25	30	40	50
Control-untreated	140	20	2.7	0.9
Nonwoven (similar to Example 2)	6000	360	41	7.7

Woven (similar to Example 3)	3900	1100	58	7.9
Woven-nonwoven laminate (similar to Example 4)	4000	600		7.2

The results indicate that peening with wheels of this invention improves fatigue life by a conservative factor of from about 8 to 35, with the greatest improvement being shown at lower stress values. The results also show that peening with the wheels of this invention permits a given part to be subjected to a higher stress level than one which is not peened, while maintaining the same useful life.

We claim:
1. As a new article of manufacture, having particular utility for fabricating flaps for use in a unitary self-contained portable rotary peening device, having an annulus of said flaps united at their inner ends to a rigid core, comprising in combination:

- a nonwoven lofty sheet material having a thickness of about one centimeter, a tensile strength of about 16 kg/cm and being formed of randomly disposed crimped nylon filament segments having diameters of 40-200 microns;
- relatively smooth, hard impact-resistant inorganic spheroidal peening particles having average diameters in the range 0.1 - 2.5 mm, dispersed throughout said sheet material in an amount equal to about 400 - 700 cc/m² of sheet surface; and
- a tough strong elastic adhesive, having an ultimate elongation of at least 100%, bonding said filament segments to each other at loci of intersection and also bonding said particles to said fibers while surrounding more than half of the effective diameters of said particles.

2. The sheet material of claim 1 wherein the adhesive is a chain-extended polymer of tetrahydrofuran selected from the group consisting of the reaction product of isocyanate-terminated polytetrahydrofuran prepolymer and methylene dianiline and the reaction product of an amine-terminated polytetrahydrofuran prepolymer and a bisphenol A-type epoxy resin.

3. The sheet material of claim 1 wherein the adhesive is a blend of phenolic resin and rubbery butadiene: acrylonitrile copolymer.

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