Metal Improvement Company, Inc.

Review of Shot Peening Technology

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As much as shot peening has been used in the past, there still is no non-destructive method of determining the quality of the peening on a given part. Because of this, the benefits of shot peening have not been included in the "Design Allowables". Recently, the picture has changed dramatically with the introduction of "Computer Monitored Shot Peening" (CM-SP) which, in fact, is the title of a new AMS specification being prepared by AMEC for the SAE. Use of CM-SP has already permitted the extension of the overhaul period of a recently introduced jet engine and the prospect of being able to take similar advantage in the design allowables for other engines, airframes, and landing gear, is creating considerable interest in the industry.

Aircraft hardware, because of the overriding necessity to save weight under dynamic loading conditions, is usually designed to fatigue criteria rather than to ultimate strength. Metal fatigue is caused by cyclic tensile stresses, usually highest at the surface and concentrated by notches, holes, physical damage, etc. Metal fatigue is further aggravated by the effects of environment (corrosion fatigue); or by residual tensile stresses caused by welding or grinding, for instance; by localized wear (fretting fatigue); or by rolling pressures (contact fatigue). Even metallurgical coatings such as plating or flame deposition, can cause a severe reduction in fatigue strength. Metal fatigue most often initiates as a microscopic crack at the surface after many load cycles and propagates until the part fails. Another stress-related mode of failure of great concern to the aircraft designer is stress corrosion cracking. The combination of environmental conditions (airborne salt, for instance), a susceptible material and a surface static tensile stress (residual or applied) can also cause failures over time.

In all the above modes of failure the common denominator is tensile stress, a stress which, in effect, pulls the surface apart in a propagating crack. Conversely, a compressive stress, which can be thought of as causing the surface to push together, will prevent surface cracks from initiating and/or propagating. Shot peening is the most economical and practical method of ensuring surface residual compressive stresses.

Computer Monitored Shot Peening
AMEC Writes New AMS Specification

Recently, computers have been added to shot peening machines to provide greater reliability by fulfilling three basic functions:
1) computer numerically controlling (CNC) the relative movements of the parts and the peening nozzles or wheels, 2) monitoring variables

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Titanium wing box structure after shot peening; for Navy F-14 Tomcat aircraft.

Table 1. Computer monitored shot peening parameters as listed in new AMS specification under preparation.

<table>
<thead>
<tr>
<th>Process Parameters</th>
<th>Process Limits</th>
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<tbody>
<tr>
<td>Shot Flow</td>
<td>± 5%</td>
</tr>
<tr>
<td>Air Pressure/</td>
<td>± 5%</td>
</tr>
<tr>
<td>Wheel Speed</td>
<td>± 1% RPM</td>
</tr>
<tr>
<td>Air Flow</td>
<td>± 5%</td>
</tr>
<tr>
<td>Nozzle and/or Wheel Translation Speed</td>
<td>± 0.1 in/min.</td>
</tr>
<tr>
<td>Sequential Nozzle and/</td>
<td>± 1 sec.</td>
</tr>
<tr>
<td>or Wheel Shut Down</td>
<td>± 2%</td>
</tr>
<tr>
<td>Turntable RPM</td>
<td>± 2%</td>
</tr>
<tr>
<td>Part RPM</td>
<td>± 1 inch/min.</td>
</tr>
<tr>
<td>Conveyor Speed</td>
<td>± 1%</td>
</tr>
<tr>
<td>Peening Cycle Time</td>
<td></td>
</tr>
<tr>
<td>Nozzle/Wheel Position</td>
<td></td>
</tr>
<tr>
<td>Repeatability</td>
<td>± 0.062 inch</td>
</tr>
</tbody>
</table>

"Surface enhancement from CM-SP increased life cycles and FAA approval was awarded."

Space and weight saving design criteria of the helicopter engine left little room for major changes; so the direction taken by the manufacturer was to improve resistance to fatigue in life limited turbine discs and cooling plates. Computer controlled calibrations were added to shot peening machines and an extensive test program was implemented. With the surface enhancement brought about by the Computer Monitored Shot Peening (CM-SP) the necessary increased life cycles were attained and FAA approval was awarded. The upgraded engine today is powering a growing number of commercial aircraft.

Obviously, if shot peening was to be relied upon to this extent, it would be absolutely necessary that every part be peened as specified and tested. Computer Monitored Shot Peening (CM-SP) has been employed to furnish this reliability. Essentially, the computer monitors a series of pre-set limits on machine variables (see Table 1) during the peening operation. If any parameter goes out of limit the computer shuts down the machine and the fault is displayed on the monitor and on the printout. The fault can then be corrected and the process continued. This is particularly useful since much of the shot peening on the engine is performed inside small holes, only 0.300 inch (7.62 mm) in diameter where visual inspection is very difficult.

The new AMS specification at the time of writing, is in the final review stages under the temporary designation of Draft B87BC—"Computer Monitored Shot Peening" but will likely have the final designation of AMS 2432. The new specification, even without the sections specifically dedicated to computer monitoring, is by far the most comprehensive on shot peening to date.

From a practical standpoint, controlling the shot peening with computers has several advantages to both the prime and the processor, far beyond the obvious one of increased reliability brought about by total repeatability. Inspection time is considerably reduced, for instance, on the internal peening of 30 foot (9.14 m) long helicopter rotor blades. Set up times can similarly be reduced. Less time is employed in intensity verification after the first process development. On the other hand, because of increased quality requirements, the cost of peening media (purchased to a new AMS 2431) will be higher, but this pales to insignificance when compared to the economic gains presented by weight savings in aircraft components or by extending the intervals between overhauls.
INTENSITY

Very soon after shot peening was first instituted on valve springs at the GM Tech Center in the early 1930's, it became necessary to find a means of measuring the energy being delivered by the shot to the part. Actually, the real and most useful parameter to be measured would be the effect of that energy upon the part, but that problem has not been solved to this day, in any practical form. The system devised by John O. Almen, which now bears his name, measures the relative energy which then can be extrapolated into the depth of the compressively stressed layer on the given part.

Energy, as every schoolboy knows, is the product of mass and velocity \(E = \frac{1}{2}MV^2\), but what we are really interested in here is transferred or absorbed energy, which then requires that we consider two more factors: hardness of shot and angle of impingement. Almen's system is elegant in its ability to gather these four factors into a single number and does so in a simple manner that can be used on the shop floor rather than in a metallurgical laboratory.

Almen was interested in shot peening springs so he devised some coupons of flat spring steel. These are held in a block by four screws and the exposed side is placed in the shot stream. Usually, the blocks must be mounted on a scrap part in such a way as to represent the critical surfaces of the part. When the coupons are fully covered with peening impressions (determined by a saturation curve), they are removed from the blocks. The action of the peening causes the coupons to arc (convex on the peened side). The arc height is then measured on a special depth gauge to give us the intensity number. Tables are used to relate this number to the depth of the compressively stressed layer as a factor of the hardness of the part. However, on springs (of the same hardness as the coupons or "Almen strips") there is a 1:1 relationship between the arc height on the "A" strip and the depth of compression. The "A" strip is the most commonly used but a thicker "C" strip and a thinner "N" strip are used to measure higher and lower intensities, respectively.

COVERAGE

A parameter that is actually more difficult to measure is 'coverage'. Also, there is much confusing thought and literature about shot peening coverage—even many of the specifications that deal with shot peening are incorrect. The problem becomes serious because many engineers consider the intensity (probably because it is expressed in thousandths of an inch) to be very critical and pay little attention to coverage. The fact is that, in most cases, 10% more or less intensity will not hurt, but 10% less than 100% coverage can be disastrous, particularly where stress corrosion cracking is concerned.

Coverage is a parameter that is strictly related to the hardness of the part and, to some extent, to the hardness of the shot. It has very little to do with intensity and practically nothing to do with the Almen Strip, except in one case. By using spring steel, Almen gained two advantages: one, he engineered the "A" strip so that the arc height corresponds to the depth of the compressive layer on spring steel and two,

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Shot Peening Intensity and Coverage: Which is Which and Why?

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Exposure to the shot stream creates residual stresses which cause the Almen test strip to curve upwards. The arc height is interpreted as shot peening intensity.
PEENSCAN® reveals whether 100% coverage has been reached

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because the strip and the springs are of the same hardness, "saturation" peening time on the Almen strip corresponds to "100% coverage" peening time on the springs, provided both the strip and the springs are peened under the same conditions. What about materials of different hardness? This is where the confusion sets in.

Let's look at aluminum first: it is much softer than spring steel. At the same intensity (impact energy), a single piece of shot will create a much larger dimple on aluminum than it will in the harder spring steel. "Coverage" is defined as percent of surface obliteration by peening dimples; 100% coverage is the point where the surface of the part is totally covered with overlapping dimples, in the minimum exposure time. So, if the peening time to reach saturation (100% coverage) of the Almen strip is 4 minutes, what should it be on the aluminum part? I would start with 1 minute and examine the part to determine if the dimples overlap totally. If not, I would increase the exposure time until they do; but the time will be much less than that required to reach saturation of the Almen strip. Don't worry if you exceed the minimum time: if the shot quality is good (no broken pieces) and the exposure time is not several times what it should be and the intensity is correct, no harm will be done. The danger is in insufficient coverage.

Now let's look at a carburized and hardened gear at 62 HRC. Following the same rationale, the dimples on the hard gear will be much smaller than on the Almen strip. You know that you must increase the exposure time to get many more dimples so that they overlap. Right, but how much? On a gear that hard, it is almost impossible to see the dimples even at 10x magnification. As a solution to this problem, Metal Improvement Company uses a patented system called Peenscan. Peenscan employs a fluorescent lacquer that is applied to the gear prior to exposure to the shot. The peening removes the laquer in proportion to the percentage of coverage and examination of the part under black light quickly reveals whether 100% coverage has been reached. Peenscan is used on the set-up piece and then repeatability is ensured by the use of automated or even computer monitored shot peening machines.