Shot Peening of Springs—a Case Study

John Cammett

Acknowledgments: The investigation that formed the basis for this article was instigated by the author in cooperation with four organizations that participated in experimental efforts as follows: the leaf spring manufacturer (leaf spring peening and fatigue testing), Electronics Inc. (media inspections), Lambda Research Inc. (residual stress measurements, metallography and microscopy) and Progressive Technologies (experimental peening trials). The contributions of all involved are highly valued and appreciated by the author. Additionally, the author acknowledges the combined efforts of Dave Barkley and Kathy Levy, with The Shot Peener magazine, to enhance the figures and graphs of the article.

Introduction

This article presents the initial findings from a peening optimization study in which improvements in peening processing and the durability of leaf springs were the ultimate aims. The project has not been completed, but there are valuable lessons already and these are highlighted in this article.

The leaf spring material was AISI 5160 steel, a nominally 1% Cr, 0.6% C steel, commonly used for springs. During the manufacturing process prior to peening, the steel was quenched and tempered to achieve hardness in the range of 380-420 BHN. Per the manufacturer's customary practice, peening of the tension surfaces of spring leaves was performed as the final step in the manufacturing sequence. As a quality control measure, the manufacturer's practice was to perform fatigue life testing of individual leaves sampled from production runs. The basic motivation for this study was to determine factors that influenced fatigue life results with an eye to potential process improvements that could enhance spring performance. This was entirely at the manufacturer's initiative because there were no reported indications of field failure problems in any of the product lines.

Characterization of Existing Peening Process

Shot peening of the tension surfaces of individual spring leaves was performed via wheel peening equipment at an Almen intensity of 6-7C using medium hardness S390 cast steel shot to a minimum of full (100%) coverage as attained by one pass through the peening equipment. Per the author's observation, Almen saturation was achieved within the first pass. No increase in Almen arc height was observed after multiple passes. Full coverage on spring leaves was also achieved during one pass as determined by on-site direct observation/inspection using a 10X magnifier and later verified by microscopic observations at greater magnification. The peening wheel speed and conveyer belt speed were not variable and, therefore, were fixed for the process.

The manufacturer had neither a screen separator for media size control nor a device such as a spiral slide for media shape control. Media maintenance practice simply involved adding new media at intervals to make up for fallout losses during processing. The lack of media maintenance was apparent from the appearance of the in-use media as evidenced by the visually observable variability in particle size and shape. The size distributions of the in-use and new media on hand at the manufacturer's site were determined by standard sieve Ro-Tap testing and microscopic analysis per requirements of AMS-S-13165.

Author's note: The spring manufacturer was not subject to any specification requirements for peening. This information is presented here for reference purposes only.

Ro-Tap screening results from in-use and new media are tabulated below. Discrepancies between results and AMS-S-13165 requirements are highlighted in red. As can be seen, the new media size distribution conformed reasonably well to requirements with a slightly excessive amount of coarse particles retained on the 14 mesh screen. Otherwise the size distribution was within requirements. On the other hand, the in-use media displayed a marked bias of fine media particles. Photographs (10X original magnification) of representative media samples are shown in the insets of Figure 1 (page 10).

Not only was the in-use media overpopulated by fine particles, a large proportion of these were apparently the result of particle fracture. As indicated, the new media had an acceptable number of discrepant particles while the in-use media had an excessive number of discrepant particles. Easily inferred from this evidence was that lack of a screen separator and/or shape control device allowed discrepant and deteriorated media to be retained for use in the process.

In-Use Media Size Distribution

Sieve #	% Retained	Cum % Retained	AMS-S-13165 Requirement
12	0		0
14	3.5	3.5	2% Max*
16	9.5	13.0	50% Cum Max
18	21.8	34.8	90% Cum Min
20	6.7	41.5	98% Cum Min
Pan	59.5		2% Max

New Media (S390) Size Distribution

Sieve #	% Retained	Cum % Retained	AMS-S-13165 Requirement
12	0		0
14	2.8	2.8	2% Max*
16	44.0	46.8	50% Cum Max
18	51.9	98.7	90% Cum Min
20	0.1	98.8	98% Cum Min
Pan	0.30		2% Max

* Red indicates requirement violation

The surface texture of the sample peened with in-use media was much more irregular than the texture of the sample peened with new media. The new media peened surface had many more regular shaped and smooth impact impressions than did the in-use peened surface. The differences in surface texture were easily interpretable as to cause from the differences in particle size distributions and numbers of discrepant particles highlighted in the insets. Not only was the surface appearance different, the sample peened with in-use media had many secondary cracks (red arrows in Figure 1) adjacent to the main fracture after fatigue testing. The sample peened with new media had no cracks other than the main fatigue crack. There was also a fatigue life difference of about 50% in favor of the sample peened with new media. Numerous secondary fatigue cracks are often indicative of either relatively high cyclic stress or surface damage/impairment. Logically, in the present case it was a matter of surface impairment from the in-use media because the new media producted no secondary cracks after testing. Both samples were tested under the same loading conditions.

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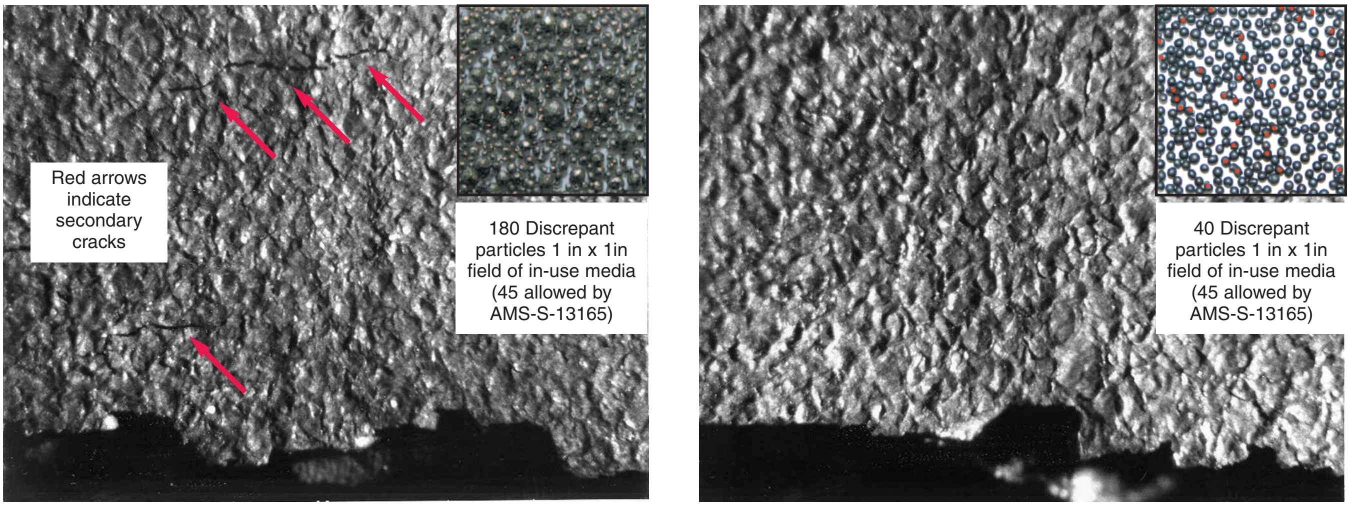

Figure 1: Surfaces Peened with In-Use Media (left) and New Media (right). Insets show media samples. Red dots indicate discrepantly-shaped particles.

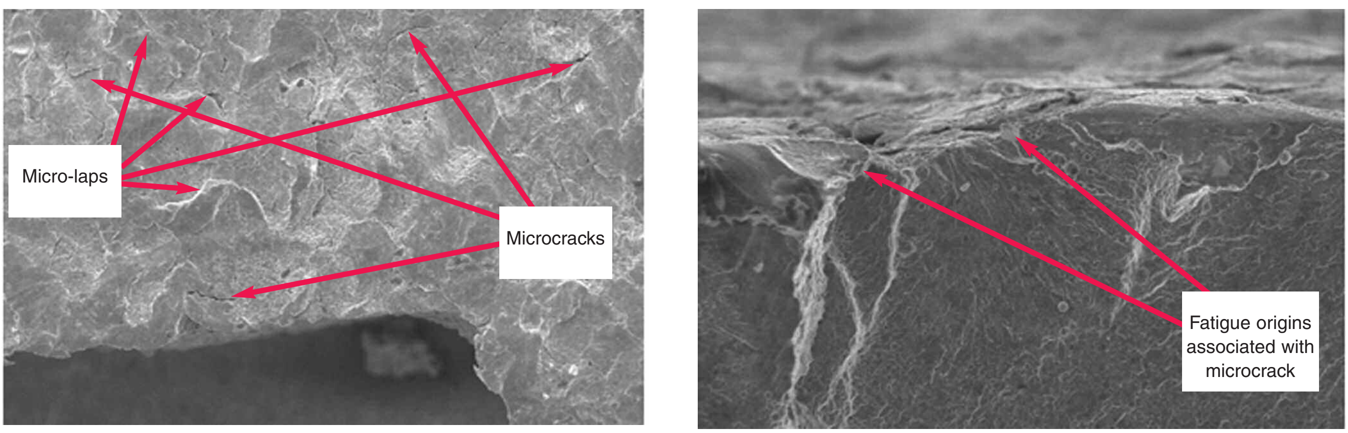

Figure 2: Micro-laps and Microcracks on Peened Surface (left SEM photo) and Fatigue Origins Associated with Microcrack (right SEM photo)

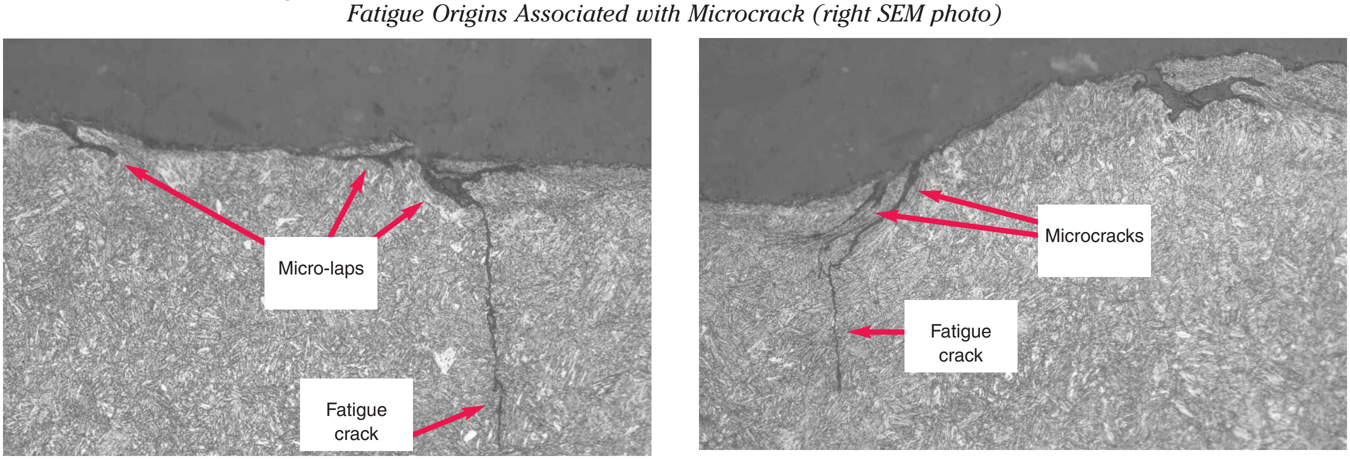

Figure 3: Metallographic Sections Showing Fatigue Cracks Emanating from Micro-Lap (left photo) and Microcrack (right photo) on Peened Surface

Scanning electron microscopic observation and metallographic sectioning through fatigue origin areas revealed further evidence of impairment of the surface peened with in-use media. As shown in Figures 2 and 3, fatigue initiation sites were associated with micro-laps and microcracks on the peened surface. Fatigue cracks that initiated on the surface of samples peened with new media exhibited no evidence of association with similar defects. Further discussion of fatigue behavior will occur in the next section.

Additional evidence for the influence of poorly-maintained in-use media as a depressant of fatigue life lay in the residual stresses induced in surface layers. Figure 4 shows the residual stress-depth distributions, obtained by x-ray diffraction analysis, from samples peened with in-use and with new media. As easily seen, the surface and near surface compressive stresses for the in-use media peened sample were much less in magnitude than the new media peened sample to a depth of about 0.015 inches

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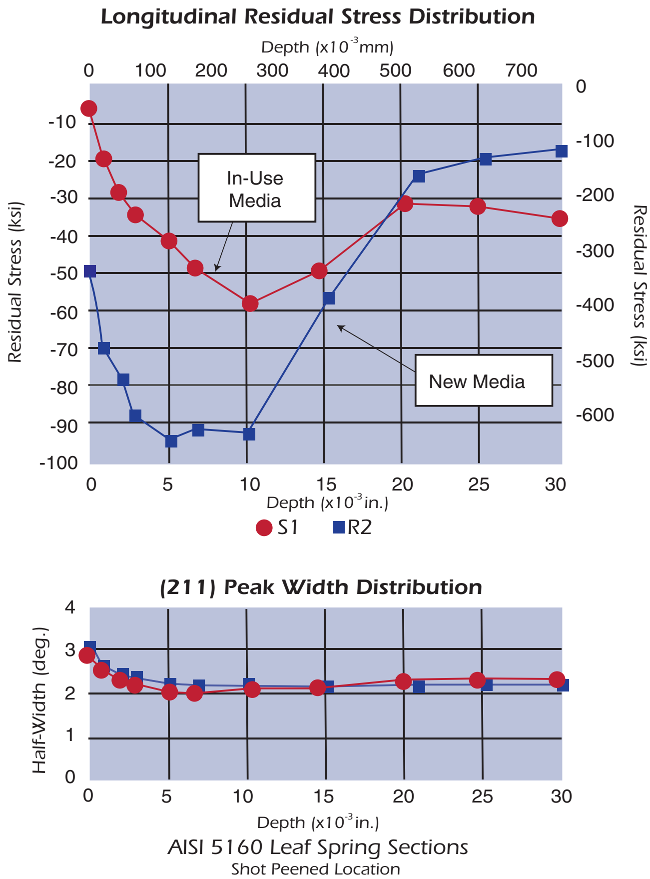

Figure 4: Residual Stress - Depth and X-ray Peak Breadth-Depth Distributions

beneath the surface. Because of the similarity in peak breadth-depth distributions, it was inferred that the larger size particles in the in-use media were dominant in producing deep residual stresses whereas the finer and misshapen particles were dominant in inducing surface damage that was responsible for reducing fatigue life.

Fatigue Life Analysis

The author analyzed all fatigue life results generated by the spring manufacturer in 2006 and in 2007 to date. As indicated previously, the author had examined some of the 2006 samples, finding greater evidence of surface micro-laps and other peening surface damage in samples peened with poorly-maintained vs. new media. It was inferred that the greater incidence of surface damage in the sample peened with in-use media was responsible for the observed lower fatigue life. In addition, the author suspected that excessive peening intensity and coverage may also have contributed to low fatigue life. Accordingly, peening of some samples at lower intensity (12A) and controlled coverage was performed at an external source. Life results from these samples were indeed greater than from the 2006 samples, but the magnitude of improvement was disappointingly small. Further disappointment was that samples peened and tested in 2007 exhibited somewhat greater fatigue lives than those peened under well-controlled conditions.

Observations from the available fatigue life results served to explain the otherwise somewhat difficult to rationalize and disappointing fatigue results. There were differences in hardness among samples and these differences contributed to life differences as revealed by the trend shown in Figure 5. Greater life was observed with increasing hardness. This trend only partly explains life differences among samples; however, the effect represented a confounding influence on interpretation of results based upon differences in surface condition.

One could probably perform a hardness-based normalization of results to improve life comparison; however, this was deemed futile because there was an even greater confounding influence present. This was not so easily resolvable. The samples in the current investigation had been tested at fairly high stress levels and, thus, life differences were masked within the "mud" of normal fatigue scatter, at least a factor of two or more in fatigue life. Historic fatigue S-N curves from leaf springs shown in Figure 6 (see reference in figure caption) serve to illustrate this effect. The author placed the dashed red circle on this figure to represent the regime of test results from the current investigation. As may be seen, the regime of current results lays in an area of convergence of S-N behavior. The very important inference from this is that normally expected fatigue life scatter (factor of 2-5) could not be expected to permit discrimination among surface treatments unless statistically large numbers of samples were tested. Certainly, the one or two samples per condition tested currently did not represent statistically large numbers. Another testing alternative would be to test at lower stress levels where the greater divergence of fatigue lives would likely permit discrimination among surface treatments. Neither testing of large numbers of samples nor testing at much lower stress levels was economically viable within the scope of this investigation. The fixed cyclic test frequency capability of the test apparatus was 0.5 Hz. Thus, the typical time duration of tests, including setup, was of the order of a day. Neither running large numbers of such tests of this duration nor running tests at lower stress levels to attain ten times greater lives was deemed economically viable. Hence, the idea of attempting to optimize peening parameters via fatigue life results from testing was abandoned. A specimen testing rather than component testing approach might have been undertaken, but this too was deemed economically unviable within constraints of the investigation.

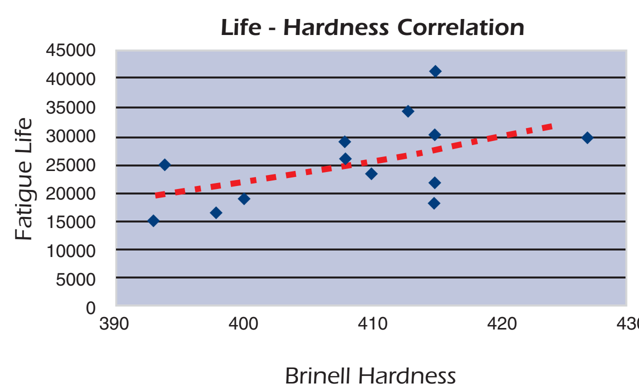

Figure 5: Leaf Spring Fatigue Life-Hardness Correlation 2006-2007 test results

Peening Parameter Investigation

Further investigation was done as to the effects of peening intensity, coverage and media size on compressive residual stress magnitude and surface roughness of the leaf spring material. The table on page 8 shows combinations and values of the parameters selected.

Surface roughness data are summarized in Figure 7, a plot of surface roughness vs. coverage for the various intensities and media sizes employed. The data show generally slight downward

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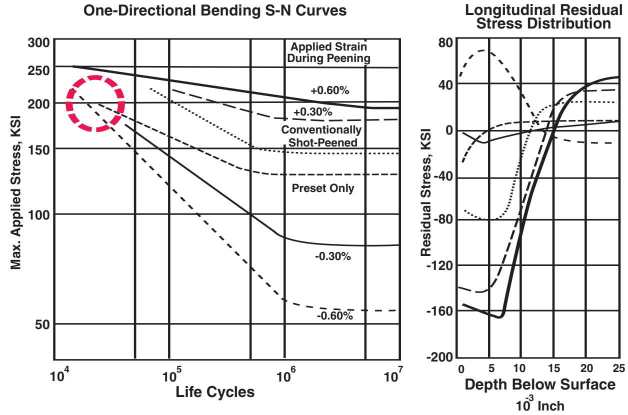

Figure 6: Historial Leaf Spring Fatigue Data.
Ref. ***Stresses and Fatigue in Metals****, Rassweiler and Grube eds., Elsevier Publishers, New York, NY*

	1	2	3	4	5
Media	S460	S460	S330	S330	S550
Pressure (psi)	15	50	18	60	27
Flow Rate (lb/min)	25	20	30	30	27
Nozzle	3/8" short V	5/16" long V	3/8" short V	3/8" long V	3/8" long V
Intensity	10.4A	6.5C	9.6A	5.6C	5.9C
%Coverage*	80,100,200	80,100,200	80,100,200	80,100,200	80,100,200

*One sample at each indicated coverage with other parameters fixed

trends with increasing coverage for given intensity and media size (i.e. surface roughness) declined with coverage increasing from 80 to 100 to 200%. Apparently the increasing number of repeated impacts at many sites served to "flatten" surface details, though the effect on roughness was deemed modest. The effect on roughness of media size at a given intensity was opposite to expectations. For a given intensity, logically one would expect a greater roughness based upon the physical requirement that a smaller particle must produce a deeper impression to have the same effect as a larger particle to produce the same intensity. Comparison of the positions of the yellow and dark blue curves representing nearly the same intensity (9.6 & 10.4A) indicates that the smaller media (S330) produced smoother surfaces than did the larger media (S460). Likewise, comparison of the bright blue and violet curves representing nearly the same intensity (5.6 & 5.9C) indicates again that smaller media (S330) produced much less roughness than larger media (S550). Curiously, an intermediate size media (S460) at a comparable intensity (6.5C) produced lower roughness than either larger or smaller media, a mixed bag for certain. The effect of intensity irrespective of media size was also a mixed bag. Here, perhaps not surprisingly, the greatest roughness was experienced for one of the greater intensities (5.9C, violet curve); however quite surprisingly, the least roughness was experienced for an intermediate intensity (13A, brown curve). The author assures the reader that the peening trials represented here were very carefully performed under computer monitored and controlled conditions, supported by appropriate Almen saturation and coverage determinations and with pedigreed media.

In most instances, surface residual stress magnitude from peening is more important than surface roughness or, if roughness must be reduced, a slight amount of post-peening metal removal will serve needs. Indeed, such material removal is likely also to remove peening-induced microlaps and enhance fatigue performance. Thus, if it comes to a choice between residual stress and roughness considerations, one should opt for the

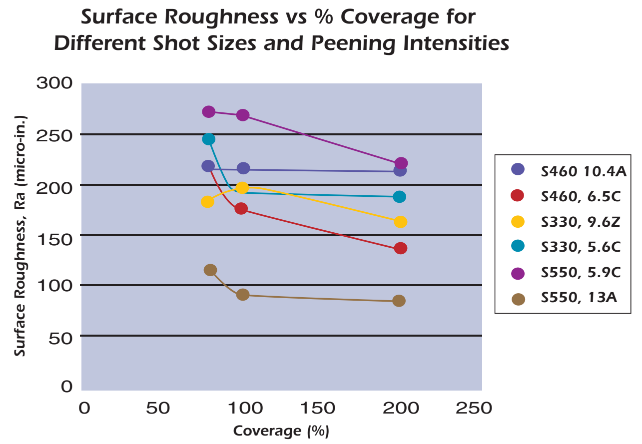

Figure 7: Surface Roughness Results from Peening Trials

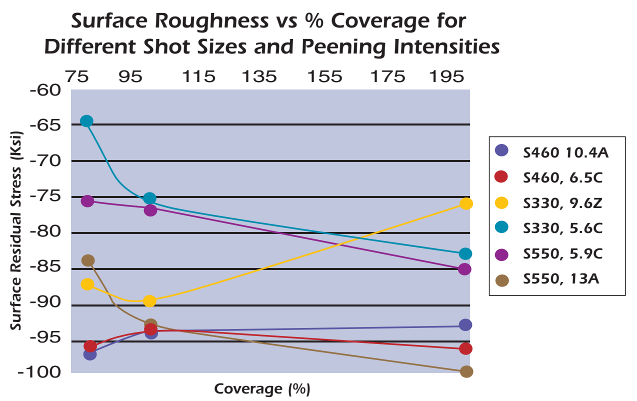

Figure 8: Surface Residual Stresses Resulting from Peening Trials

peening treatment that creates the greatest residual stress magnitude and then rely on appropriate post-peening surface treatment to achieve the desired surface finish, if necessary. Surface residual stresses resulting from the peening trials are summarized in Figure 8.

While not clear cut in all instances, greater surface residual stress magnitude was favored by peening at lower intensity. Interesting was that the best residual stress magnitude resulted from peening with the parameters, 13A intensity and S550 media, that also produced the lowest surface roughness. The effects of media size were generally mixed while the effect of coverage in nearly all cases showed a modest trend of improvement in residual stress magnitude with increasing coverage.

Summary and Recommendations

This investigation revealed that fatigue test lives from spring leaves peened via the original process were dominated by fatigue crack initiation from peening defects, namely microlaps and microcracks, induced by peening. These defects were principally the result of peening with poorly-maintained media having substantial content of broken and subsize particles. The manufacturer's fatigue life results appeared to be influenced by material hardness whereby greater hardness within the normally produced range tended to give greater fatigue life. Moreover, historic data on leaf spring fatigue also indicated that the fatigue test regime was at a level which precluded good discrimination of process effects on fatigue life. Economics prevented rectification of the latter problem and further fatigue testing has not

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been done. Additional peening trials were performed to investigate the effects of media size, peening intensity and coverage on surface roughness and surface residual stresses. Results showed that roughness and residual stress magnitude were generally favored by intermediate intensity in the range investigated, and by greater coverage over the range investigated although the latter effect was modest. The effect of media size over the range investigated was a mixed bag.

Recommendations for process improvement to the leaf spring manufacturer from results of this investigation were as follows:

- Acquire online screen separator capability for media maintenance or switch to conditioned cut wire media to greatly reduce media particle breakage.
- Reduce peening intensity somewhat from 6-7C to 12-14A. This should also serve to reduce media breakage.
- Change media flow rate and/or conveyor speed to ensure coverage within the 100-200% range.

The leaf spring manufacturer has implemented several changes including the use of conditioned cut wire media, moved the average spring hardness to the upper end of the scale and added speed controllers to the conveyor and wheel. Further fatigue testing over time hopefully will demonstrate life benefits

John Cammett Dr. John Cammett, Materials Engineer/ Metals Branch Chief, recently retired after more than 15 years service with the U.S. Navy (Navair) in the In Service Support Center to the Fleet Readiness Center East, Cherry Point, North Carolina. His more than forty-year professional career has also included materials engineering and management positions at the General Electric Company, Evendale, Ohio; Metcut Research Associates Inc. and Lambda Research Inc, Cincinnati, Ohio. His areas of expertise at Cherry Point included analysis of aircraft component failures, aircraft mishap investigations, development of repair/rework process methods and technical support of depot manufacturing/ rework/repair operations, surface integrity investigations and metallurgical applications. A Registered Professional Engineer, Dr. Cammett is a fellow of ASTM, past Chairman of Committee E-9 on Fatigue, Life Member of ASM International and past chairman of the Cincinnati Chapter, also a member of the International Scientific Committee for Shot Peening and a conferee of the 2006 Shot Peener of the Year Award. In "retirement", Dr. Cammett is currently involved in training and consulting activities with Electronics Inc., Nadcap auditing plus other research and consulting activities in the private sector. He will be an instructor at all four of the 2008 EI workshops. Dr. Cammett may be contacted via cell phone at 1-910-382-5771 or email at pcammett@ec.rr.com.

2007 Shot Peener of the Year: Ken I'Anson

Ken I'Anson received the 2007 Shot Peener of the Year award at the U.S. Shot Peening and Blast Cleaning workshop in Arizona.

The Shot Peener magazine was pleased to award Ken I'Anson the 2007 Shot Peener of the Year award at the 2007 U.S. Shot Peening and Blast Cleaning workshop. The award is given to persons that make significant contributions to the advancement of shot peening in either commercial or academic venues.

Ken has been involved in the shot peening industry from the equipment side for 27 years. His experience is unique in that it has covered both centrifugal wheel peening and compressed air nozzle peening. He is a Sales Engineer for Progressive Technologies and focuses on airframe and land-based turbine shot peening applications. He not only understands the mechanics of the machines but the process of peening and the requirements for successful peening results.

Ken has contributed many articles and papers for the EI Shot Peening Workshop manuals and has attended the Workshops since the beginning in 1990. He has obtained Level 3 Exam certification at the EI workshops. He is also a frequent contributor to The Shot Peener magazine and the forums at www.shotpeener.com.