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The Shot Peener

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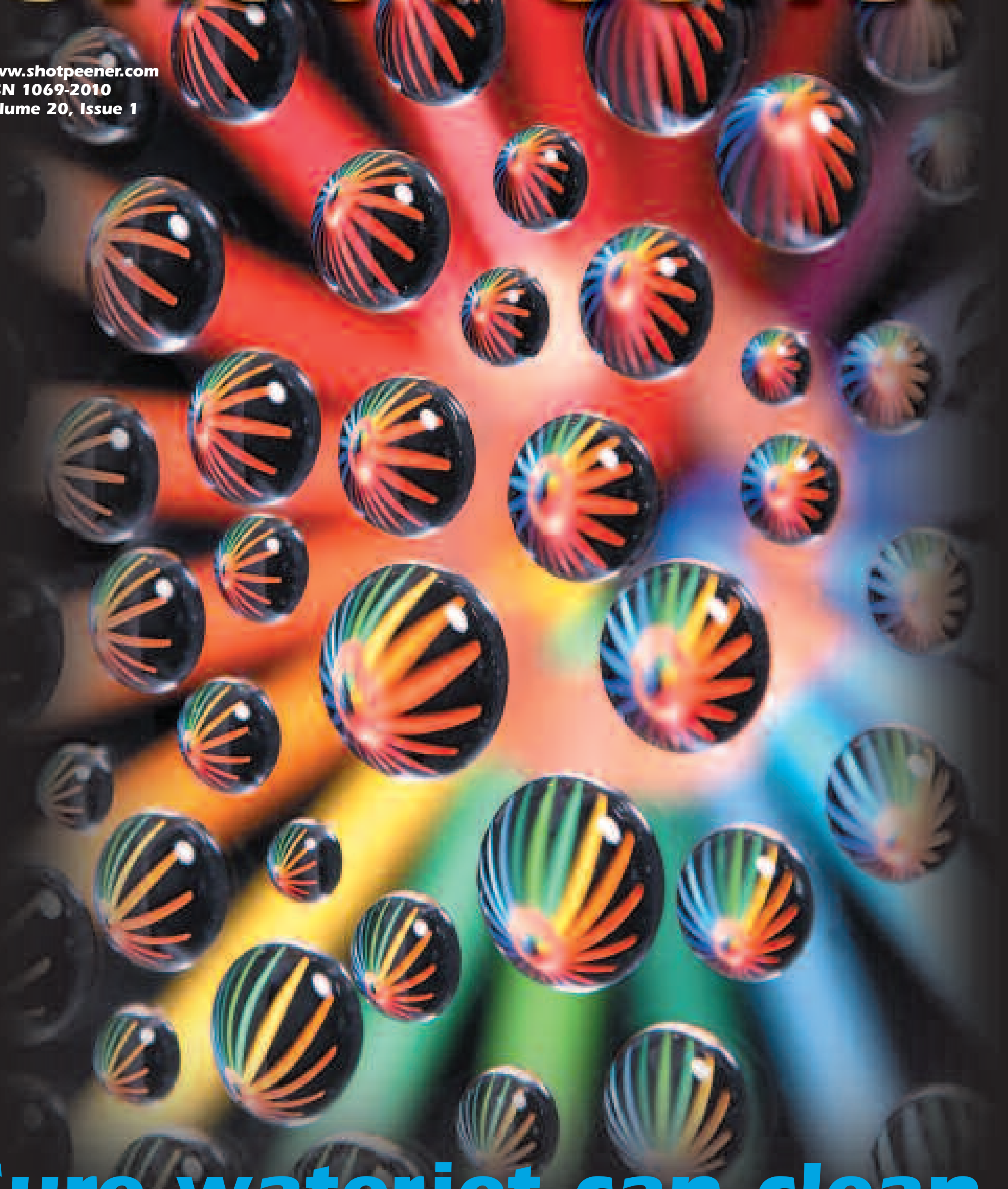

Sure waterjet can clean, but can it peen?

Plus, our focus on Nadcap:

- Friend or foe to the supplier?
- Audits from Nadcap's perspective
- Spec conformance and equipment design

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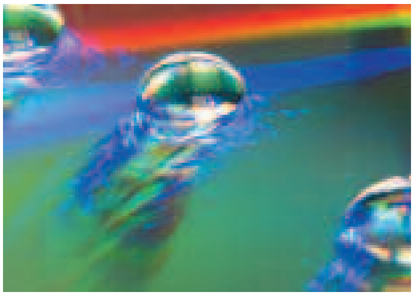

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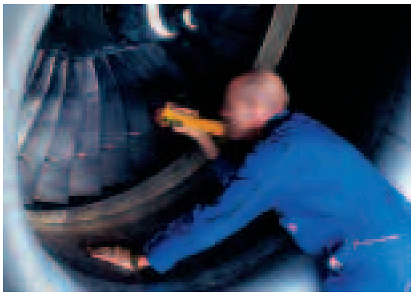

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Photo: Aircraft structural peened by reciprocating multiple nozzles. Provided by Wheelabrator Group.

A note from a reader:
"Thanks for providing a forum in The Shot Peener for Dr. Kirk and other authors to advance our understanding of the science of shot peening. I look forward to every issue."

—John E. Ullman
Principal Engineer
Honeywell Aerospace

The Shot Peener (ISSN 1069-2010), in print since 1986, is a quarterly publication from Electronics Incorporated with a circulation of over 4500 readers worldwide. It is dedicated to raising the awareness and appreciation for the shot peening and abrasive blast cleaning industries.

Input is always welcome—send comments and suggestions to:
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Telephone: 1-574-256-5001 Email: shotpeener@shotpeener.com Web site: www.shotpeener.com

Sure waterjet can clean, but can it peen?

Given enough pressure, water can clean with laser-like intensity and accuracy. Force it through an orifice with a diameter of 0.007" to 0.015" (0.18 - 0.4 mm) at pressures between 30,000 - 60,000 PSI (2000 - 4000 bar), and water becomes a high velocity beam that can quickly remove difficult coatings including adhesives, epoxies, felt metal, grease, paints, resin composites, rubber, and thermal spray coatings such as abradables, ceramics, cermets, and metallics. Ultra-high pressure waterjet (UHP waterjet) cleaning is a relatively new technology—it didn't achieve recognition as a viable production tool until the 1980s—but it has already distinguished itself with several advantages over traditional abrasive and chemical cleaning methods:

- Doesn't remove the base metal
- Doesn't create a surface deformation
- No abrasive deposits left on parts or in machinery
- Eliminates the need for abrasives disposal
- Uses an environmentally-friendly, reusable media - water!
- Faster removal rates than chemical removal processes

Shipyards, highway departments, electric utilities, and chemical plants are just a few of the markets for UHP waterjet contractors. Nuclear power plants are a particular niche for waterjet cleaning: The plant's radioactive water can be used to prep steel water vessels for repainting and then kept in the plant after the project is over—there is no need to dispose of radioactive grit or sand. UHP waterjet is also enjoying increased demand from manufacturers of maintenance systems for military and civil aerospace companies. The aerospace engine rebuild and overhaul industry requires the removal of coatings for inspection, restoration and coating replacement and the benefits of UHP waterjet cleaning closely match its needs. The process removes plasma coating and chemical barriers and no deformations are created. Plus, it provides the highest processing precision and the procedure is environmentally-friendly.

Headquartered at Schiphol Airport Amsterdam, KLM Engineering and Maintenance offers customized MRO (Maintenance, Repair and Overhaul) support to a broad group of airlines around the world. KLM utilizes UHP waterjet cleaning before shot peening engine parts. According to Marcel van Wonderen, Master Engineer Process, Equipment & Materials Development for KLM, "80% of all aircraft engine parts that receive a new thermal spray coating will be shot peened after they have been waterjet cleaned." The shot peening process has two important functions:

1. to compensate for possible tension stress induced by the UHP waterjet cleaning and
2. to introduce compressive stress to compensate for tension stress which will be induced by new thermal spray coatings.

The line of events for part repair are:

- UHP waterjet cleaning
- shot peening
- grit blasting
- thermal spraying

Mr. van Wonderen is an active member of the Water Jet Technology Association (www.wjta.org). In fact, he was one of the authors of a paper on abrasive waterjet cleaning titled "Controlled HVOF Hard Coatings Removal Method" that received the Best Research Paper award at the 2005 WJTA Conference. (Abrasive waterjets use water to accelerate abrasive particles to cut through much harder materials than can be removed by waterjet cleaning.) As an early adopter of waterjet processes, Mr. van Wonderen is now watching the development of an innovative new process: waterjet peening. "Waterjet peening is very interesting in the medical industry for applying compressive stress into artificial implants like titanium hip joints. The problem with conventional peening is the fact that it always leaves tiny small residues in metal surfaces, which is unacceptable on implants. Waterjet peening will never leave residues," says Mr. van Wonderen.

A seal (an aircraft engine part) is being placed on the fixture of a machine at KLM. The UHP waterjet cleaning machine will strip the seal's abradable coating.

According to numerous studies from around the world, many researchers share Mr. van Wonderen's interest in waterjet peening. Waterjet peening holds tremendous promise as a clean, efficient and environmentally-friendly surface treatment method. The application of the high pressure waterjet to induce compressive residual stress to enhance fatigue strength is not new; the topic was presented in an ICSP-2 paper by Djozíc Salko in 1984[1]. Compared to shot peening, waterjet peening has these benefits: It shows negligible influence on surface roughness and topography, the improved surface finish of the waterjet peened surface increases the crack initiation time, and the complete and uniform coverage of the given surface area results in more uniformly induced residual stresses in the subsurface.

As stated by Mr. van Wonderen, UHP waterjet peening is indeed of interest to the medical *Continued on page 6*

[1] Salko, D. "Peening by Water", Proceedings of 2nd International Conference on Shot Peening. ICSP-2, Chicago, Illinois pp./37-38. Paper is available at www.shotpeener.com (paper #1984052)

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industry. Dwayne Arola, PhD and his colleagues at the University of Maryland Baltimore County are researching a new manufacturing process call Hydroxyapatite Waterjet Peening (HAWP) that is envisioned for use in the surface treatment of metal implants. HAWP is a combination of high-pressure waterjet and shot peening. High-pressure waterjet is laden with bioactive particles (hydroxyapatite) and directed at the substrate at a selected orientation of jet impingment. The goal of the team's research is to develop a surface treatment process that provides the critical requirements necessary for long-term success of metal orthopaedic implants without the addition of a coating. Preliminary results suggest that such a surface treatment may actually enhance the growth and function of bone forming cells.

Michael Jenkins, PhD, in the Department of Mechanical Engineering at the University of Detroit Mercy, is studying the effects of high pressure water peening on the high cycle fatigue life and fatigue crack propagation behaviors of various plastically-deformable metal alloys. He believes that waterjet peening is an innovative manufacturing technology for selectively surface treating machine components susceptible to failure from cyclic fatigue including gear teeth shafts, leaf springs, etc. "The small size of the impinging waterjet allows surface treatments to locations on components inaccessible to conventional shot peening, such as the roots of gear teeth, while minimizing changes in surface texture due to deformation," he says.

Will waterjet peening secure a place in the surface treatment industry's toolbox? We believe so and will continue to report the developments in future issues of The Shot Peener. We commend the researchers that push the boundaries of current technology—their work creates new opportunities for our industry and even more importantly, new products that will benefit everyone.

Resources and contacts:
Marcel van Wonderen - email: mseg-van.wonderen@klm.com
Waterjet Technology Association - www.wjta.org
Dwayne Arola, PhD - email: darola@engr.umbc.edu
Michael Jenkins, PhD - email: jenkinsm@udmercy.edu
The Shot Peener Online Library - www.shotpeener.com

The following are the Abstracts and Conclusions from several papers on waterjet peening from researchers that are testing the potential of the process. These papers are available in their entirety from the online library at www.shotpeener.com.

ULTRA HIGH PRESSURE WATERJET PEENING PART I: SURFACE TEXTURE

2001 WJTA American Waterjet Conference
August 18-21, 2001 Minneapolis, Minnesota

S. Kunaporn and M. Ramulu - University of Washington
Seattle, Washington, USA

M. Hashish and J. Hopkins - Flow International
Kent, Washington, USA

ABSTRACT

An experimental study was conducted to investigate the influence of high-pressure waterjet peening conditions on surface characteristics of a 7075-T6 aluminum alloy. Surface profilometry and scanning electron microscopy (SEM) were used in characterizing the surface texture and topography. Surface characteristics in terms of surface texture on peened specimens in relation to peening conditions were analyzed and discussed. It was found that the magnitude of erosion on material surface by the impingement of high-pressure waterjets was strongly dependent on the applied peening conditions.

CONCLUSION

Results from the investigation of surface characteristics showed that changes of surface produced by high-pressure waterjets were strongly dependent on peening parameters. It was found that waterjets did induce plastic deformation on material surface. A decrease in compressive residual stress was expected at longer peening time and shorter standoff distance when material removal occurred. Statistical functions have been used to distinguish and define appropriate standoff distance for waterjet peening. Results also showed that the changes in surface roughness and topology are directly influenced by the kinetic energy that has been transferred to target material. Therefore the same surface characteristics on the target material are obtained by using an equal of energy supplied by the jet. These results might be useful information in waterjet peening application and further study.

ULTRA HIGH PRESSURE WATERJET PEENING PART II: HIGH CYCLE FATIGUE PERFORMANCE

2001 WJTA American Waterjet Conference
August 18-21, 2001 Minneapolis, Minnesota

S. Kunaporn and M. Ramulu - University of Washington
Seattle, Washington, USA

M. Hashish and J. Hopkins - Flow International
Kent, Washington, USA

ABSTRACT

Waterjet peening has recently emerged as one of the alternative surface treatment processes to improve the fatigue life of the components. Part I of this experimental study has been concentrated on surface characteristics of waterjet peened material. In this part of the study, unnotched hourglass shaped circular cross section test specimens were fabricated and surface treated for selected waterjet peening conditions. Completely reversed rotating bending fatigue tests were conducted on peened aluminum specimens to evaluate fatigue performance (S-N curves). Fracture surfaces were evaluated by scanning electron microscopy (SEM) to identify the fatigue mechanisms. Results show that waterjet peening can enhance the fatigue strength by 20 - 30% to that of unpeened Al7075-T6 material.

CONCLUSION

Fatigue performance study of waterjet peened specimens under ultra-high pressure conditions by using a fan-jet nozzle was conducted on 7075-T6 aluminum alloy. Within the experimental conditions used in this study, the following conclusions were made:

1. Waterjet peening is capable of inducing surface plastic deformations similar to shot peening. Plastic deformation in waterjet peened test specimens caused fatigue crack to initiate in theinterior of test specimens.
2. The degree of fatigue life improvement by waterjet peening was found to be dependent on peening conditions i.e. jet pressure, standoff distance, nozzle type, jet velocity and peening time. This study showed that the fatigue improvement by waterjet peening could be achieved. *Continued on page 8*

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3. Surface erosion and pits induced due to the impact of the jets has a marked influence on fatigue strength of material. To improve fatigue strength by waterjet peening, it is important that peening conditions must be appropriately chosen to ensure that waterjets will not induce surface erosion.

4. The maximum fatigue improvement found in the water-peened specimens of high strength alloy (Al-7075-T6) was about 25%, which is comparable to that of shot peened specimens of the same material.

MATHEMATICAL MODELING OF ULTRA HIGH PRESSURE WATERJET PEENING

2003 WJTA American Waterjet Conference
August 17-19, 2003 Houston, Texas

S. Kunaporn - Walailuk University
Nakhonsithammarat, Thailand

M. Ramulu - University of Washington
Seattle, Washington, USA

M. Hashish - Flow International
Kent, Washington, USA

ABSTRACT

Waterjet peening is a recent promising method in surface treatment. It has potential to induce compressive residual stresses that benefit the fatigue life of materials similar to the conventional shot peening process. However, there are no analytical models that incorporate process parameters, i.e. supply pressure, jet exposure time, and nozzle traverse rate etc., to allow predicting the optimized peening process. Mathematical modeling of high pressure waterjet peening was developed in this study to describe the relation between the waterjet peening parameters and the resulting material modifications. Results showed the possibility of using the proposed mathematical model to predict an initial range for effective waterjet peening under the variation of waterjet peening conditions. The high cycle fatigue tests were performed to validate the proposed model and fatigue test results showed good agreement with the predictions.

CONCLUSION

The mathematical modeling based on the multiple impacts of the jets has been proposed to estimate the contact pressure and the feasible peening range. Fatigue results showed that the proposed mathematical model might be a practical tool to predict the initial waterjet peening range since results showed some agreement between the fatigue study and the proposed model. Fatigue life improvement by waterjet peening was observed in the specimen waterpeened under the effective conditions predicted by the proposed model. Fatigue results did show that the viability of the proposed mathematical model that predicted the effective range for waterjet peening. With this observation, the proposed mathematical model could be used as the initial means to find out the optimal range for waterjet peening. However, more studies on other metals are necessary to perform in order to validate the model.

AN ANALYTICAL MODEL FOR PREDICTION OF RESIDUAL STRESSES IN WATER JET PEENING

2003 WJTA American Waterjet Conference
August 17-19, 2003 Houston, Texas

G. Vikram and N. Ramesh Babu - Indian Institute of Technology Madras, Chennai, India

ABSTRACT

In the present work, an analytical approach is proposed to estimate the residual stresses induced on the surface of a material treated by water jets. The dynamic response of material to jet impact, assuming elastic behavior of the material, is determined using the Navier's equation. Owing to the axi-symmetry of the jet loading, the equations are transformed into Hankel space using zero and first order Hankel transforms and are solved. Due to the absence of a closed form expression for the Inverse-transform of the solution, suitable engineering approximations are made to solve this problem. The results thus obtained are used to determine the strain field, which in turn is used to determine the zone of plastic deformation. Using von Mises yield criterion and assuming kinematic hardening of the material, the residual stresses on the surface of the material are evaluated. The predicted stresses are compared with the results published in the literature.

CONCLUSION

In this work, an analytical model to predict the residual stresses in water jet peening is outlined. The material response to jet loading in terms of displacements is estimated using the Navier's equation. To take advantage of the axial symmetry in the problem, the equations are transformed and solved in the transformed space. It is shown that a Laplace transform followed by a Hankel transform of appropriate order can be used to reduce the complex governing equations into wave equations with a single variable dependency. To counter the problem of non existence of closed form solutions for Inverse-transforms, engineering approximations to the solution are made. It is shown that the error associated with this approximation is less than 10%. The analysis showed that this approximation introduces a greater error in the frequency component than in the magnitude of the solution and that there is no associated error in the steady state solution. Hence it is concluded that the approximation will not alter the predicted residual stresses to a considerable extent.

The displacement field thus obtained is used to estimate the maximum values of strains and stresses in the given domain assuming the material to be elastic in nature. The stress field accounting for the plastic nature of the material is determined using the von Mises yield criterion and stress field predicted from the displacements. Finally, the residual stresses induced on the surface are estimated by superimposing a reverse load of equal magnitude and determining the resultant stress. The proposed approach gave results, which are in good agreement with the results predicted using finite element methods. This approach gives the advantage of reduced computational time along with good accuracy of prediction in comparison to the finite element approaches.

In order to model the process more accurately for utilizing it to predict the optimal water jet peening parameters, attempts are being made to account for the energy loss in plastic deformation. It is also proposed to extend the model to a moving jet in further work.

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A STUDY ON RESIDUAL STRESS IMPROVEMENT BY WATER JET PEENING

Masahito Mochizuki, Kunio Enomoto and Shinji Sakata
Mechanical Engineering Research Laboratory, Hitachi, Ltd., Japan

Koichi Kurosawa, Hideyo Saito and Hiroshi Tsujimura
Hitachi Works, Hitachi, Ltd., Japan

Kozo Ichie
Uozu Factory, Sugino Machine, Ltd., Japan

1993 Conference Proceedings ICSP-5, (p.246-255)

ABSTRACT
This paper describes the effects of residual stress improvement by water jet peening, which is expected to improve the residual stress on various component surfaces in nuclear power plants as a preventative maintenance technique for preventing stress corrosion cracking and fatigue fracturing. Numerical analysis is performed to clarify the fundamental mechanism of residual stress improvement, and various tests are done to determine the fundamental characteristics of and suitable conditions for the residual stress improvement. Fundamental tests confirm the applicablility of the water jet peening technique for nuclear power plants that can improve residual stress.

CONCLUSION
Water Jet Peening has been developed as a preventive maintenance technique for nuclear power plants particularly to prevent stress corrosion cracking and fatigue fracturing. Numerical analysis was performed to clarify the fundamental mechanism of stress improvement, and various tests were performed to apply this technique to the components of nuclear power plants.

(1) Numerical analysis shows that high water jet pressure influences the compressive residual stress due to the plastic deformation of the surface.
(2) Water Jet Peening effectively improves the residual stress on the heat-affected zones of the weldments.
(3) Jet distance, hydraulic pressure of the water jet pump, peening time, and nozzle angle were studied to effectively improve residual stress with this method.
(4) A thermal aging test with the Larson-Miller parameter P shows that Water Jet Peening repeated three times will maintain about -200MPa of compressive residual stress for 40 and 80 years.
(5) Water Jet Peening treatments prevent stress corrosion cracking in the components of nuclear power plants.

Nuclear power plants are potential markets for waterjet cleaning and peening.

Nadcap: Friend or foe to the supplier?

Nadcap is a cooperative industry effort to improve quality, while reducing costs, for quality assurance throughout the aerospace and defense industries.
—Nadcap's marketing materials

The Nadcap program is administered by the not-for-profit Performance Review Institute (PRI). PRI's stated goal is to ensure that aircraft and aero-engines are of the highest quality to ultimately protect the public. Before Nadcap, the responsibility for assuring subcontractor quality was shouldered by individual aerospace companies. Nadcap believes that it will assist the industry in working together to end the duplication of effort, the inconsistent application of standards and the unnecessary costs associated with redundant audits. Nadcap goes on to state that it will actually reduce redundant auditing in the aerospace industry because it:

- Establishes stringent industry consensus standards that satisfy the requirements of all participants
- Reduces routine special process audits
- Conducts more in-depth, technically superior special process audits
- Improves supplier quality throughout industry through stringent requirements
- Reduces costs through improved standardization
- Utilizes technically superior auditors to assure process familiarity
- Provides more frequent audits for primes, fewer audits for suppliers

PRI is achieving a global presence. PRI now has offices in China, Japan, and the United Kingdom; its headquarters is in the United States. If you are a supplier, or want to be a supplier, to the growing list of Nadcap-subscribing primes (prime contractors) that includes Air Force, Boeing, Airbus, Rolls-Royce, Honeywell, Bombardier, BAE Systems, Rockwell Collins, Cessna Aircraft, Eaton Aerospace, GE Transportation, Industria de Turbo Propulsores, MTU Aero Engines, Northrup Grumann, United Technologies and Lockheed Martin, they will require you to achieve Nadcap accreditation through an audit. (A complete primes list is available at www.pri-network.org.)

The Nonconventional Machining and Surface Enhancement (NMSE) Task Group conducts audits to demonstrate compliance to the SAE AS 7116 (Non-conventional Machining) and SAE AS7117 (Surface Enhancement). Nadcap audits are expensive, lengthy and the necessary preparation is taxing for any size supplier. Audit results have shown that flowdown of customer specification and Nadcap requirements into workstation instruction are the most common non-conformance to the Aerospace Standards. This has serious implications for the industry as a whole. The NMSE Task Group requires detailed workstation instructions (routing, technique sheet, etc.). Most suppliers are not used to this level of detail and initially struggle to meet Task Group/Nadcap flowdown expectations. While it is generally found that suppliers are meeting process and specification requirements, failing to have detailed workstation instruction leads to variations in application and greater chance for process and specification non-compliances.

PRI attended ICSP-9 to share the latest information about Nadcap with the aerospace industry, meet with technical experts and learn about current developments within this dynamic field.
—Arshad Hafeez
Director of Global Business Operations, Industry Managed Programs, Research & Development for PRI

Nadcap staffed a booth at the recent International Conference on Shot Peening in Paris. Joanna Leigh, the Nadcap European Operations Specialist, was on hand to meet with conference attendees and share information. She distributed a brochure that outlined the programs Nadcap has developed to meet the needs of suppliers:

- **Nadcap meetings.** Nadcap meetings take place every quarter (January, April, July and October). Primes and suppliers are encouraged to attend as the meetings are intended to improve understanding and experience of the Nadcap process and provide valuable learning and networking opportunities. Meeting details, including agendas and minutes are posted at www.pri-network.org
- **Nadcap Customer Support Initiative (NCSI).** The NCSI is a free web-based training program developed by PRI in conjunction with the Nadcap Management Council. The goal of this training is to improve supplier readiness for Nadcap audits. The presentation offers pre- and post-audit advice, an overview of the Nadcap process and a review of the additional tools available to assist you. Each session is hosted by a Nadcap User member and they are informative and interactive.
- **eAuditNet.** eAuditNet is an online system for everything relating to Nadcap audits. You can learn more about how the Nadcap process works and participate in these ways: From requesting a quote to scheduling the audit; from carrying out thorough audit preparation to responding effectively to non-conformances after the audit in order to gain accreditation promptly. Subscribers can monitor the real-time progress of their suppliers to ensure compliance with Nadcap standards. Auditors also use eAuditNet extensively to view audit history and file the reports on a completed Nadcap audit. In addition, eAuditNet also contains the online QML, which is the searchable manufacturer's list of certified Nadcap suppliers.
- **Supplier Support Committee**. As major participants in the Nadcap system, suppliers voice their opinions and make suggestions for improvement to the Nadcap process through the Supplier Support Committee (SSC). The SSC mission is to represent the supplier community and work with the Nadcap Managment Council (NMC) to enhance the effectiveness

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and economic value of the Nadcap system for the mutual benefit of suppliers and primes. The SSC is made up of active Nadcap accredited suppliers who are willing to help new suppliers through the process, as well as assisting experienced suppliers to establish, maintain and improve their accredited processes. The SSC meetings take place at the quarterly Nadcap meetings and all suppliers are invited to attend.

▪ Before the audit checklist

Nadcap provides these steps and timeline as a guideline only; all may not apply to your facility.

☐ Contact PRI and access eAuditNet
☐ Ensure that you hold AS/EN/JISQ9100 or AS9003 or AC7004
☐ Schedule audit and obtain checklists
☐ Educate and train staff
☐ Attend Nadcap Customer Support Initiative training
☐ Check documentation compliance
☐ Attend a Nadcap meeting
☐ Review training
☐ Carry out a self-audit including job audits
☐ Complete RCCA* and monitor effectiveness
☐ Obtain external assistance if appropriate
☐ Check documentation compliance
☐ Educate and train staff on any revisions
☐ Revise RCCA* as appropriate
☐ Ensure staff training and records are maintained
☐ Attend a RCCA* seminar
☐ Conduct another self-audit
☐ Complete RCCA* and monitor effectiveness
☐ Provide staff training
☐ Contact the auditor and provide documentation
☐ Ensure that the audit fee has been paid

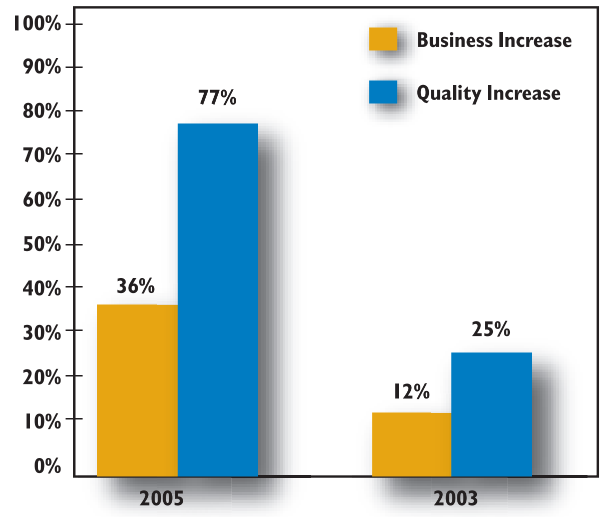
*RCCA stands for Root Cause Corrective Action. This should be carried out on an ongoing basis to maximize the effectiveness of your self-audit and root cause corrective actions.

> The analysis from the 2005 supplier survey will help set the agenda for improving the Nadcap process for the next two years.
>
> **—Ed Engelhard**
> **Supplier Support Committee Chairman**

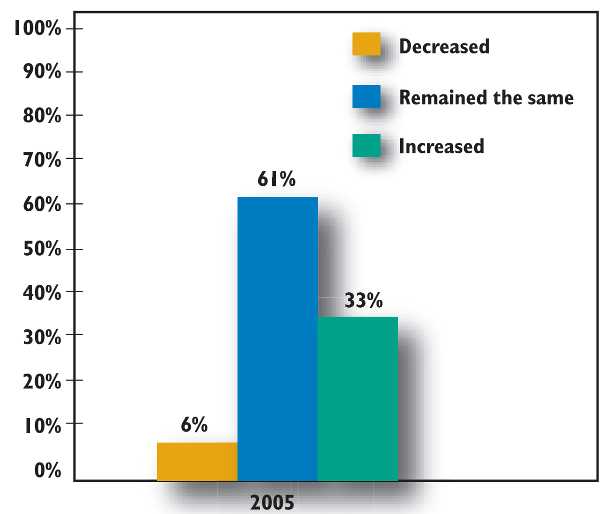
The Nadcap Supplier Support Committee (SSC) sponsored two supplier surveys, in 2003 and 2005, to address the following issues: Redundant Audits, Flow Down, PRI, Participation/Awareness, Software, Pre-Audit, Training and General Comments. 398 suppliers took part in the 2005 survey. SSC brought together a team of suppliers, primes and PRI staff to analyze the 2005 data and then determine the health of each Nadcap program surveyed and recommend appropriate action. (Request the complete survey report by emailing The Shot Peener at shotpeener@shotpeener.com)

The following graphs highlight crucial information from the 2005 survey and how it compares to the 2003 survey. (Please keep in mind that these surveys were completed by suppliers in Heat Treating, Materials Testing Laboratories, Non-Destructive Testing, Sealants, Welding, and Nonconventional Machining and Surface Enhancement, the classification that includes shot peening.)

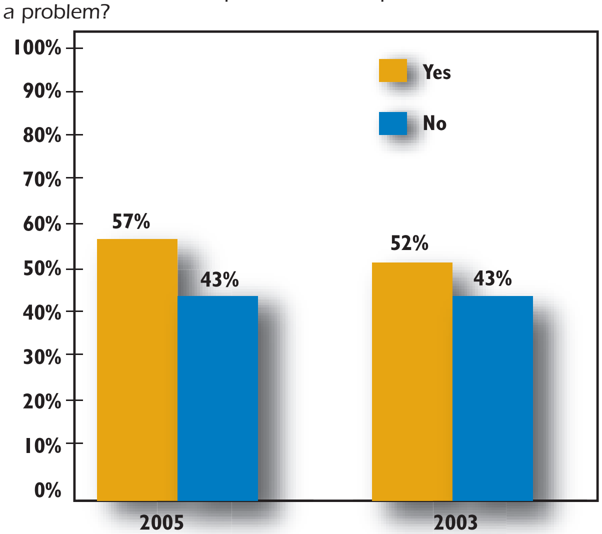
Survey question: If your company has been accredited for one year or more and your company measures business and/or quality trends, have you seen improvements in this area(s) related to your Nadcap accreditation(s)?



Survey question (new in 2005): In relation to overall prime surveillances, has the number of audit days:



Survey question: Do you find flowdown of specifications, their revisions, and other requirements from primes and their sub-tiers a problem?



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As you can see from the graphs, accredited suppliers are enjoying a significant increase in business and quality, but the number of audit days and the flowdown of specifications, their revisions, and other requirements from primes and their sub-tiers remain areas of concern.

> Wouldn't my time be better spent in the shop working on continuous improvement activities?
>
> ***—Walter Beach***
> **Quality Assurance Manager**
> **Peening Technologies**

Since the survey results weren't specific to the shot peening industry, we wanted the first-hand experiences of a shot peening supplier. In 2002, Peening Technologies of Connecticut, a Hydro-Honing Laboratories Inc. company, became the first Nadcap shot peening accredited supplier. In addition to this Nadcap accreditation, Peening Technologies has received these additional significant milestones: The company's AS-9100-compliant quality assurance system has been approved by major aerospace manufacturers; the Connecticut facility became FAA Repair Station KJ1R272K in 1971 and earned JAA approval in 1993; in 2004, Peening Technologies of Georgia, Inc. received Nadcap accreditation and became FAA Repair Station G89R878X in 2005. Peening Technologies has 23 prime approvals. Peening Technologies offers shot peening, abrasive blasting and surface enhancement services to the aerospace, automotive, power generation and oil and gas exploration industries.

Walter Beach, Quality Assurance Manager of Peening Technologies, says that Nadcap is a great program if it accomplishes two things:

- raises the bar in quality so that all shops meet a minimum standard, and
- reduces the number of redundant audits.

Mr. Beach has not seen the results he has hoped for in either area. Regarding the quality issue, he believes that the FAA could benefit from utilizing Nadcap. His biggest disappointment is consistent with the results of the 2005 supplier survey—the number of redundant audits has not been reduced in his business. "In 2001, we had 45 audits. In 2005, we had 50 audits. And some of the primes are asking the same questions over and over again," says Mr. Beach. "Wouldn't my time be better spent in the shop working on continuous improvement activities?" According to Mr. Beach, one prime has done a great job of embracing Nadcap and uses it properly—General Electric.

Mr. Beach hopes that primes will eventually work with only two specs: AMS 2430 and AMS 2432. He says that not only are there too many specs to maintain, but many of the primes' specs are old. The way he copes with the numerous specs is to maintain the highest spec in his plant.

Mr. Beach takes advantage of one of the best vehicles available to him to voice his concerns—he attends Nadcap meetings. Nadcap **expects** suppliers like Peening Technologies to be involved. For example: Suppliers are eligible to become voting members in each Task Group (TG) and voting members in the Nadcap Management Council (NMC) where they participate with the subscribing prime contractor members and PRI management in accreditation discussions and overall program management. Suppliers are openly invited to participate in appropriate open TG and NMC sessions and ad hoc committees, expressing their opinions and offering their expertise. Supplier executives have been invited to bring their concerns directly to the program for open and frank discussions about the issues surrounding accreditation and the industry in general.

Peening Technologies continues to grow and while its success can't be directly attributed to Nadcap accreditation, the accreditation is one component of the company's continual striving for excellence that makes it a vendor of choice for the world's largest aerospace companies.

> Not everyone can make the cut. There will be that much more work for those who do.
>
> ***—Stuart Sherman***
> **Metallurgical Processing, Inc.**
> **2004 Supplier Roundtable Member**

So friend or foe? Any organization that strives to improve procedures and increase efficiency is a friend of quality-driven suppliers. Nadcap could eliminate the poor shot peening practices that have plagued the aerospace industry for years. Our recommendations are that you prepare and train for the audit to make it as smooth and painless as possible. Utilize Nadcap's numerous resources before and after the audit. If you feel Nadcap hasn't delivered on its promises, take advantage of the many opportunities to make your voice heard in the aerospace community. And then reap the benefits of being recognized as one of the top suppliers in the industry. ●

Audits from Nadcap's perspective

by Scott Nelson, Nadcap NMSE & AQS Staff Engineer

As the Nonconventional Machining and Surface Enhancement (NMSE) and Aerospace Quality Systems (AQS) Nadcap Staff Engineer, I have the opportunity to work with leaders in the aerospace industry including the Nadcap subscribing primes, special process suppliers and my fellow Staff Engineers. I work primarily with aerospace primes to develop industry standards and audit criteria to assess compliance to the customer and industry specification.

The NMSE Task Group currently performs an average of 250 – 275 audits per year across the Americas, Europe, and Asia and maintains an auditor base of eleven auditors. We also have more than 16 aerospace prime contractors who mandate Nadcap accreditation for their NMSE suppliers.

In my experience, the greatest thing about the Nadcap process and its industry-managed structure is the open communication between the primes, suppliers, staff engineers, and auditors which allows a sharing of information so all can benefit.

The Nadcap process utilizes independent contract auditors who go through rigorous screening and interviews by the Nadcap Task Group prior to approval. These auditors are an elite and professional group of which 80-100% typically hold B.S. degrees in Metallurgy/ Material Science or other relevant fields and the average years of relevant experience generally number over 30. Nadcap uses these experts to evaluate the special process suppliers to the defined Nadcap aerospace standards and audit criteria. The audit reports are submitted to the Nadcap staff engineer and reviewed for technical compliance and completeness.

The NMSE Task Group routinely studies and evaluates the most common noncompliances found during our audits and these studies have shown that flowdown of customer specification and Nadcap requirements into workstation instructions are the most common non-conformances to the Aerospace Standards, AS7116 (Nonconventional Machining) and AS7117 (Surface Enhancement). Generally, in the shot peening audits, we will see the lack of flowdown in areas such as critical process parameters (air pressure, translation rates, and coverage), set-up instructions and masking, and pre-peen inspection for sharp edges and damage and post-peen coverage inspection.

As a result of these types of audit findings, it is common to receive a root cause response from the supplier stating "operator error" or "operator failed to follow instructions" and action to prevent recurrence which states "re-trained operator". These responses are not acceptable for Nadcap and will always require further response from the supplier. It is important to realize that human error is not completely avoidable, but that it is manageable.

In the example presented above, the first thing I ask myself as the audit and root cause corrective action reviewer is WHY?

- Why was there operator error?
- Was it due to inadequate detail in the workstation instructions?
- Does the supplier provide detailed technique sheets specifying critical process parameters and tolerances?
- Are set-up sketches and other visual media given to the operators to use during processing?
- Are inspection requirements specified in the workstation instructions?

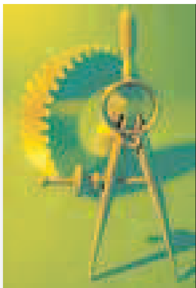
Once the supplier answers these questions pertaining to shop floor level documentation, they also need to determine whether their quality system procedure such as contract review, specification review, and planning are detailed enough to ensure consistent identification and flowdown of these critical process parameters and controls. Only when suppliers go to this level of root cause will they be able to identify their systemic problems and begin to take steps and put process controls in place to help reduce and manage operator error.

I always stress to the NMSE supplier base that it is important to give these operators correct and detailed information that they can use to ensure compliance and repeatable processes. We normally see situations where someone in the office creates travellers, technique sheets, data cards, etc., without ever going out to the shop floor and communicating with the operators and discussing concerns during the planning stages. It is easy to cite operator error, but if the operators are not given the information they need to meet requirements it is hard to totally blame the operator. The biggest faults that I see in most suppliers is the failure to involve the operators (or at least have some level of communication with them during planning), and to give operators a method of providing feedback to engineering and quality when it's found that shop floor paperwork is incorrect or not detailed enough to ensure controlled and repeatable processes.

As a staff engineer, it is still important for me to understand and promote to my auditors that all suppliers will be different and that there is no one "right way" to ensure proper flowdown and the reduction of operator error. There are different levels of technical expertise across industry, varying situations involving language barriers, different quality system structures, and one of the most important variables is management dedication and support. We realize that in some companies it may be required to have very detailed workstation instructions with visual images and precise operator instructions and in some facilities they may only require lower level general instruction. The questions we need to ask are: Are the workstation instruction adequate to ensure compliance with the customer requirements, the audit criteria, and the suppliers internal procedures; and are the operators following the instructions.

In my experience, the greatest thing about the Nadcap process and its industry-managed structure is the open communication between the primes, suppliers, staff engineers, and auditors which allows a sharing of information so all can benefit. It is my hope that suppliers take advantage of the information in this article so that we can improve the flowdown of process controls to operators and shop floor personnel. This is where the real action takes place and in most cases, these technical hands-on personnel are probably the most important assets to suppliers.

Scott Nelson is a Nadcap Nonconventional Machining and Surface Enhancement (NMSE) and Aerospace Quality Systems (AQS) Staff Engineer.



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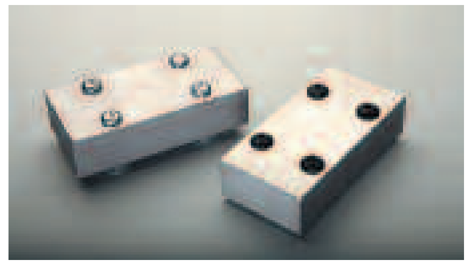

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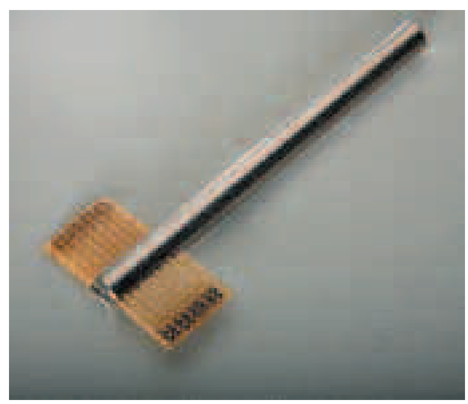

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Specification conformance and equipment design

A discussion of how equipment and process design of shot peening machinery could facilitate compliance to specifications and audit criteria such as Nadcap.

By Kumar Balan, Wheelabrator Group

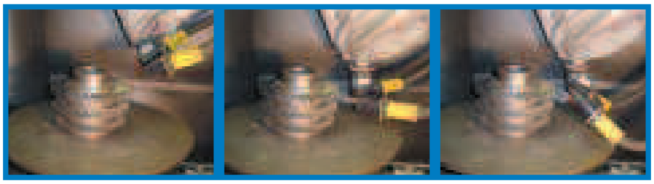
In the recent past, the shot peening group at Wheelabrator has been approached by several aerospace MRO facilities with request for peening equipment that conforms to Nadcap (National Aerospace and Defense Accreditation Program) audit requirements. To address the importance of this audit to our aerospace customers, this discussion will attempt to explain and highlight how equipment design can satisfy such a critical requirement. If appropriate steps are taken in the design of peening equipment and associated processes, conformance to specifications and audits including Nadcap will be simplified to a routine and effortless task.

The need for a unified specification was felt almost 15 years ago resulting in the genesis of Nadcap under SAE and PRI. The current audit criteria are the result of elaborate discussions over the years among various primes such as Boeing, GE Aircraft, Rolls-Royce, etc.

PRI AC7117 is the prescribed audit criteria for Nadcap. Section 4 of this document audits equipment features and surveys conformance to its various elements. Depending on the nature of the end user's existing equipment, some of the audit requirements may not be met. PRI AC7117 understands this aspect and requires the user/applicant to explain such discrepancies.

Listed below are critical aspects of the audit, each followed by the manner in which that aspect can be addressed in equipment and process design. Response to each line item is based on the machine being equipped with a PLC controller and Windows-based Operator Interface.

4.1.1: Does the equipment have the capability of mechanically moving the shot stream and/or the workpiece?



The shot stream can be moved in several ways. In an automated airblast peening machine, nozzle(s) could be mounted on a carriage/manipulator that follows defined travel paths based on inputs provided. Industrial robots could also be employed for this purpose. In a wheel blast machine, though not very common, the control cage setting could be altered on the fly to provide sweeping blast patterns.

Workpiece movements are application specific. While peening round parts such as fan disks, compressor disks and blades, the parts are independently mounted on a rotary table and spun while being peened. When processing long parts such as wing spars and other structural members, the parts are conveyed on a roller conveyor. In either case, the requirements of this audit element are well met.

4.1.2: Does the supplier check the physical characteristics of (a) nozzle and air-jet wear, (b) Almen fixture wear, (c) masking fixtures, (d) test sieves, (e) part fixtures, (f) hoses, (g) wheel condition?

These are elements from the supplier's operations and maintenance manual. In addition to mere compliance, it is to the user's benefit to adhere to the instructions.

4.1.3: Is the equipment equipped such that the air and media will not turn on unless the part and nozzle/wheel motions are also turned on?

Most automated machines are equipped with zero speed switch circuits that prevent air and media to be turned on if zero speed is detected in the drive arrangements for the nozzle and wheel motions. In addition to just satisfying this criteria, a separate circuit could ensure that the nozzle manipulator always reports 'home' before starting a new or re-starting an interrupted cycle. This could be verified by a photoeye. Given the cost of scrapping an improperly peened part, it is critical that such checks be built into the design.

4.1.4: Are all process monitoring equipment and/or gages identified as to their calibration status and current?

Automated peening systems are usually equipped with electronic or analog gages for displaying process parameters such as blast pressure, flow rate, etc. These gages are factory calibrated and typically do not require additional calibration. In addition to such gages, Operator Interfaces such as a TouchScreen or a PC monitor display nozzle position coordinates, table or conveyor speed, media flow rates, etc. Such gages only require a one-time calibration.

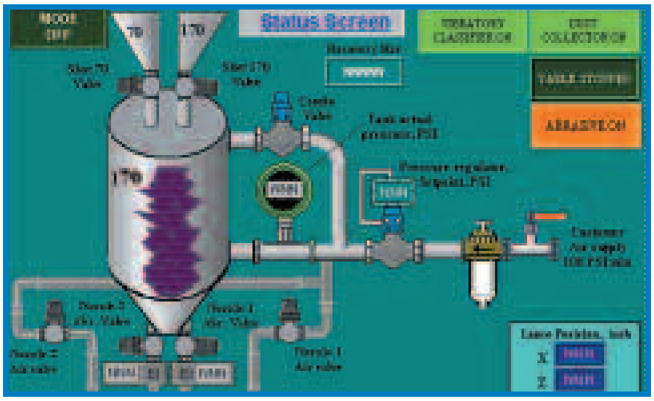
Individual user groups may have other calibration policies. For example, calibrating the flow control valves every 6 or 12 months, calibrating the test sieves every 12 months, etc.

4.1.5: Do gages used to monitor/control the process have a measurement range to cover the operating range of the equipment, and is the gage resolution sufficient?

Peening intensity is directly proportional to the blast pressure. Blast pressure requirement for most peening applications is within 90 PSI (6.2 Bars). It is therefore important to ensure that pressure gages at the minimum have an operating range of up to 100 PSI. Graduation in most analog gages is 1 PSI.

The MagnaValve, widely-used for flow control and monitoring, can display maximum media flow rates for all commercially-available blast nozzle sizes and wheel designs.

4.1.6: Is the equipment equipped with instrumentation or visual indicators that allow the operator to monitor: (a) Air pressure or wheel speed, (b) Part movement, (c) Nozzle/wheel movement?



As mentioned earlier, instrumentation in the form of proximity sensors and zero speed switches detect part and nozzle movement (or absence of it).

Visual indicators could be provided either in the form or gages or graphic displays on the operator interface screen.

4.1.7: Is the equipment equipped with media quality equipment to maintain size and shape as per the specification requirements?

Mechanical vibratory classifiers provide media size classification (100% for most airblast peening applications and a steady sampling for wheelblast applications). Media shape can be maintained, if required, by a Spiralator.

4.2.5: Is shot screening equipment integral to the shot peening media reclaim system so that the media is classified continuously?

Classification in an airblast application is usually continuous, given the lower flow rates from nozzles (when compared to wheels). In a multiple wheelblast peening system, it is usually only a sample.

Spiralator capacities are quite limited in capacity and therefore only a sample percentage (usually 10 to 25 Lbs/min) is passed through the unit.

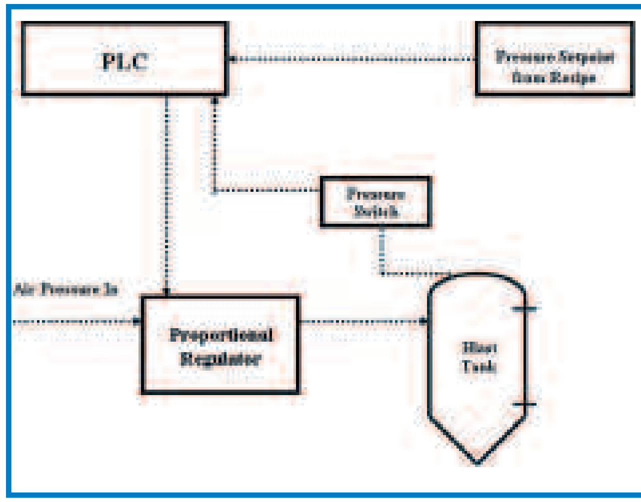
4.1.8: Does the peening equipment include a dust collector for continuous removal of dust and other fine particles during operation?

It is a requirement that all blast machines (cleaning and peening) be supplied with a ventilation and dust collection system.

4.1.10: Does the air system include low-air pressure alarms or does supplier have an air capacity management plan?

Well-designed peening systems incorporate a closed loop feedback for pressure control. This system, while satisfying the above audit criteria, operates as follows: (Please refer to line diagram)

The operator inputs the desired blast pressure as part of the technique/recipe. A pressure transducer senses the air pressure in the blast tank and compares it with the desired



setting. Any variation between the two values is automatically corrected by an Analog Proportional Regulator provided in the main airline to the blast tank.

In addition to this corrective feedback loop, sophisticated controls systems could also incorporate a setting for bandwidth values. This essentially permits the operator to set bandwidths (time delays) before triggering a fault alarm. The system could be set to shut down the process if the required pressure is not maintained within a specified time period of say 30 seconds.

4.2.3: Is the equipment equipped with the capability to shut down the process when required parameter limits are exceeded?

As explained above, bandwidth settings will permit shutting down the system in the event where the required parameter limits are exceeded.

4.2.4: Is a record of the shut down details generated for each occurrence of automatic shut down?

In addition to just shutting down the system, a record of the shut down can also be generated in the form of an 'Alarm' screen.

Summary:

The above audit criteria do not necessitate compliance to various elements but questions whether such features are available in the equipment used for peening. If not present, the audit requires the user/applicant to explain the discrepancy.

Though most specifications are open to interpretation, uncertainties can be eliminated by ensuring that the equipment supplier understands and meets requirements. ●

Kumar Balan is a Product Engineer with Wheelabrator Group Equipment/Process Design & Specification Conformance.

Accuracy of computerized saturation curve analysis

by David Kirk

INTRODUCTION

Accuracy has two components: **precision** and **bias**. Attention has to be paid to both components if we are to achieve high levels of accuracy.

Imagine that we have a digital thermometer, sensitive to changes of 0.001˚C, which *always* reads 104.167˚C±0.001˚C when its probe is immersed in boiling pure water at atmospheric pressure. That would represent perfect precision but would have a large bias of 4.167˚C and therefore poor accuracy. On the other hand, we could have a simple mercury thermometer that was only sensitive to ±0.1˚C but always read 100±0.1˚C when immersed in pure boiling water. That would represent low precision but zero bias and therefore better overall accuracy.

Our primary objective in saturation curve analysis is to determine the Almen arc height that satisfies the "10% criterion". The accuracy with which we achieve this objective depends upon three factors: the accuracy of our arc height measurements, data set characteristics and finally saturation curve analysis procedure. All three contain elements of variability (converse of precision) and bias. This article considers, quantitatively, the causes and effects of these elements with respect to the overall accuracy of saturation curve analysis.

ACCURACY OF ALMEN ARC HEIGHT MEASUREMENTS

(a) Variability

All arc height measurements have some degree of variability. Consider the two hypothetical sets of Almen arc height data, A and B, given in Table 1. These are for sets of twelve identical strips peened using the same conditions but by different operators. The objective in both cases was to impose an arc height of 0.0063". It can be seen that both operators were successful *on average*. The variability of arc heights for operator A was, however, much less than that for operator B. This difference is *quantifie*d by the respective standard deviations of 0.0001" and 0.0003". (Standard deviations are easily calculated using Excel. We highlight a cell and insert, for example, "=STDEV(A1:A12)" where A1:A12 contains our twelve arc height values.)

We do not need to understand the mathematical basis of 'standard deviation' in order to use it effectively (we can drive within speed limits without knowing how a speedometer works). The term standard deviation refers to the 'spread' to be expected from a set of values that are 'normally distributed'. 'Normal' distributions for standard deviations of 0.0001" and 0.0003" are shown in fig.1. The *area* under both curves is the same (1.000) representing the 100% probability of recording a value somewhere. We can see that the probability of obtaining a value very close to the mean 0.0063", is much greater with the smaller standard deviation than it is with the larger one. The data in Table 1 agrees with that prediction. Conversely, the probability of obtaining a value well away from the mean is much smaller with a lower standard deviation. Table 2 presents a useful quantification of that effect.

The significance of the probabilities given in Table 2 is twofold. On the one hand we should *expect* about one in three values to be one standard deviation or more away from the mean value. If someone regularly reports a lower probability than the

Table 1
Variability displayed by two sets of Almen arc height data.

Strip No.	Arc heights (inch x 1000) Set A	Set B
1	6.2	6.3
2	6.3	6.5
3	6.3	5.9
4	6.2	6.7
5	6.5	6.0
6	6.3	5.9
7	6.3	6.4
8	6.4	6.3
9	6.2	6.2
10	6.3	6.5
11	6.3	6.7
12	6.1	5.9
AVERAGES	**6.30**	**6.30**
STANDARD DEVIATIONS	**0.10**	**0.30**

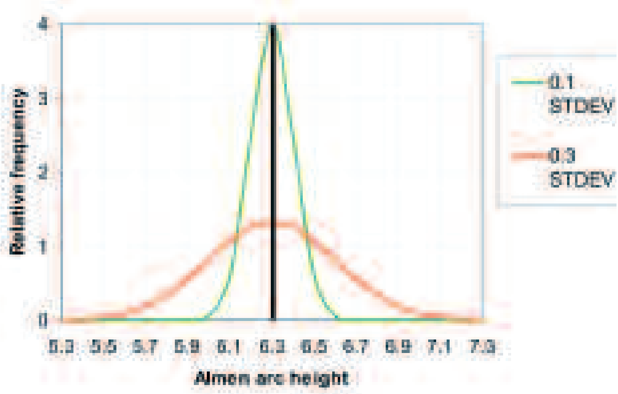


Fig.1 Spread of arc heights about a mean value of 0.0063".

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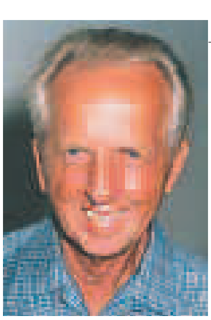

Dr. David Kirk, our "Shot Peening Academic", is a regular contributor to The Shot Peener. Since his retirement, Dr. Kirk has been an Honorary Research Fellow at Coventry University, U.K. and is now a member of their Faculty of Engineering and Computing. He is currently writing a book "The Science of Shot Peening". We greatly appreciate his contribution to our publication.

Continued from page 24

Table 2
Probability of obtaining a specific value for normally-distributed measurements.

No. of standard deviations away from the mean value.	Probability of obtaining value.
1	One in three
2	One in twenty
3	One in four hundred

'norm' then we should be suspicious! On the other hand if someone regularly reported values more than three standard deviations from the 'norm' we should be worried!

We can usefully quantify the *origin* of different values of standard deviation for Almen arc height determinations. In order to do that we use a term called "variance". Variance is simply σ^2, where σ is the standard deviation. The advantage of using variance is that total variability is simply the sum of the variances of the contributory factors. The total variability of *repeated* Almen arc height values, σ^2_T, is made up of the separate variances due to strip variability, measurement errors and variations in applied peening parameters. Hence we have that:

$$\sigma^2_T = \sigma^2_S + \sigma^2_M + \sigma^2_{AP} \quad (1)$$

where **S**, **M** and **AP** refer to strip, measurement and applied peening respectively.

Almen strips are produced to very close tolerances so that the σ^2_S contribution should normally be very small. 'Premium grade' strips will produce a smaller variance than 'standard grade' strips (other factors being equal). The σ^2_M contribution depends upon the quality of the Almen gage and the operator's skill/assiduousness. With good equipment and careful attention to detail, σ^2_M should also be relatively small. The major factor contributing to variability would then be σ^2_{AP}.

During actual shot peening there will always be some variation of the parameters that would affect strip deflection. Examples are: air pressure fluctuation, variations in flow rate and shot size (as when a batch of new shot is working its way through).

Equation (1) quantifies Almen strip measurement variability. Consider, by way of illustration, two examples A and B reflecting

Table 3 Effect of separate variabilities on total variability of Almen strip measurement.

		σ_S strip variability	σ^2_M measurement variability	σ^2_{AP} peening variability	Total variability
A (Good)	Standard deviation	0.01	0.03	0.095	**0.10**
	Variance	0.0001	0.0009	0.009	**0.01**
B (Poor)	Standard deviation	0.04	0.10	0.280	**0.30**
	Variance	0.0016	0.01	0.078	**0.09**

good and poor combinations of factors respectively. Table 3 shows the results of applying equation (1) to *hypothetical* values (expressed in units of thousandths of an inch).

It is important to appreciate that variability of data cannot be completely avoided. Data variability can, of course, be minimized by careful attention to *all three* contributory factors.

(b) Bias

One obvious source of bias is the original strip curvature or 'prebow'. This can be allowed for by 'zeroing' the gage with the slightly curved strip in place. The origins and minimization of bias with strip measurements are well-documented and therefore will not be discussed here. These include support ball wear, zero error and gage calibration over the full working range.

DATA SET CHARACTERISTICS

Important data set characteristics are: variability, number and range of the points that make up the set. All three characteristics affect the selection of fitting curve and the subsequent accuracy of saturation curve analysis. To make life complicated they all interact with one another. 'Regression' curve fitting is designed to accommodate data variability ('interpolation' merely joins data points and ignores variability). The larger the number of data points the greater will be the accuracy of the final analysis. **Data range has a profound effect on the accuracy of saturation curve solutions.** In spite of that, there is virtually no published information on the subject. Consider, for example, SAE Data Set No. 8 from Sheet 3 of the Almen Solver (downloadable from www.shotpeener.com). This data set is presented in fig.2 where a three-parameter equation has been fitted. That equation is (h = a(1-exp(-b*t^c))) where h is arc height , t is peening time and a, b and c are the three parameters. There are six data points, covering a time range from 0.25 to 4. If, however, the operator had been restricted to only four data points then a variety of saturation points would have been obtained – depending on the range covered by the four points!

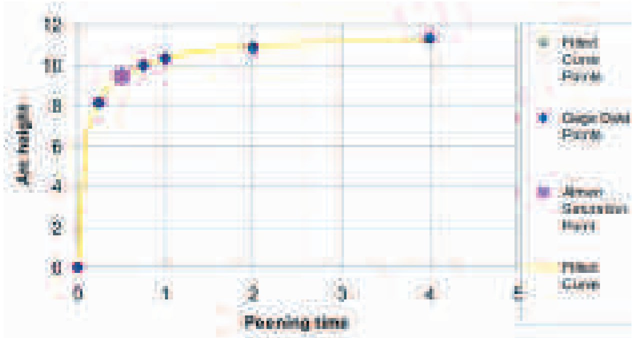

Fig.2 Three-parameter saturation curve fitted to SAE Data Set No.8.

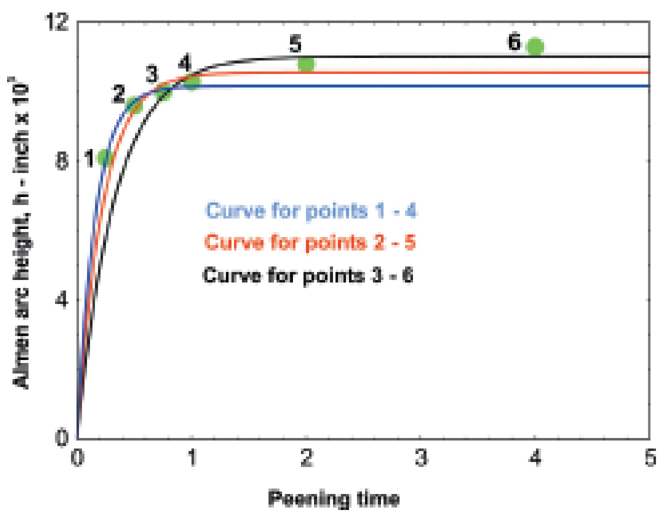

Fig.3 Two-parameter saturation curves for different ranges of SAE Data Set No.8.

This phenomenon can be illustrated by selecting different ranges of four points from Data Set No.8; for example the first four, middle four and last four. The corresponding fitted curves are shown

Continued on page 28

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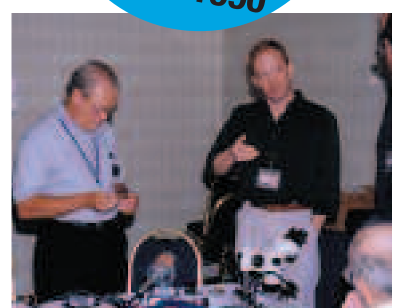

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Continued from page 26

Table 4 Saturation points for different ranges of points from SAE Data Set No.8.

Strip No.	Peening Time	Arc Height
1	0.25	8.1
2	0.5	9.6
3	0.75	10.0
4	1	10.3
5	2	10.8
6	4	11.3
Range	Saturation point height	Saturation point time
All six, 1 - 6	9.58	0.43
First four, 1 - 4	9.15	0.37
Middle four, 2 - 5	9.51	0.51
Last four, 3 - 6	9.93	0.77

in fig.3 where computer-optimized saturation curves have been drawn using a two-parameter exponential equation [h = a (1 –exp (-b*t))].

Data Set No.8 is given in Table 4 together with the saturation point values corresponding to the four curves shown in figs.2 and 3.

The consequence of using only four data points with different time ranges is that we introduce a bias to our saturation point. That bias (which is the second factor reducing accuracy) depends on the position of the four data points relative to the saturation point. The magnitude of the bias will also be affected by the curve-fitting equation that is being used. Bias can never be eliminated but having more than four data points in each set can minimize it.

The variability of the data, together with the range and number of points, affects the overall accuracy. An unrealistic exception would be if every data point had zero variability. The larger the variability of individual data points the greater is the need to have more points in each set – provided that they cover an appropriate region of the saturation curve.

SATURATION CURVE ANALYSIS PROCEDURE

(a) Curve Finding versus Curve Fitting

A clear distinction has to be drawn between curve *finding* and curve *fitting*. Curve finding involves trying to find an equation that gives a 'best fit' to our set of data points. There are computer programs incorporating a facility that allows such an equation to be found from hundreds of 'library' examples. Manual curve sketching has a similar approach in that it involves the brain in trying to *find* a 'best fitting' curve. Both bias and lack of precision are unavoidable with manual curve fitting to any given data set. Computerized curve *fitting*, on the other hand, is when a program fits our data points to a pre-determined equation. The parameters of our pre-determined equation are adjusted until the differences between our data points and those of the curve are minimized. The program, being automatic, ensures perfect precision in terms of data analysis but cannot, of course, remove bias and variability from our data.

It is only curve *fitting* that is appropriate for saturation curve analysis.

(b) Curve Equation

Our first problem is to find an appropriate equation. The general shape of a saturation curve is well known – qualitatively. Arc height initially rises quickly, then slows down rapidly and finally becomes almost constant. This observed shape is caused by the mechanisms involved in peening the strip. Each indentation causes a tiny increase in arc height, largely due to plastic deformation. Arc height should therefore *approximate* to the shape of a coverage curve (which has the well-known form: C = 100(1-exp(-b*t))) which interprets as: **h = a(1-exp(-b*t))**. The parameter "**a**" increases with size and velocity of the shot particles. Parameter "**b**" increases with shot flow rate. As peening progresses the strip work hardens so that successive indentations induce less plastic deformation and so are less effective in producing increments of arc height. Adding a "**c**" parameter to the peening time accommodates this work hardening effect. We then have that: **h = a(1-exp(-b*t^c))**. A third, minor, mechanism is a complex combination of factors that include self-annealing and work softening. This combination progressively offsets the effect of work hardening and can be represented by a linear component, **d*t**, added to the preceding equation. A 'true shape' for saturation curves can therefore be expressed in the form: **h = a(1-exp(-b*t^c)) +d*t.**

We could only expect to have a data set that gave a 'true shape' curve if the variability effect of the individual data points was virtually eliminated. That is possible if we average hundreds of repeat measurements for each set of peening conditions. Fig.4 shows a 'true shape' distribution of data points based on Wieland's published summary of hundreds of measurements. The three curves just described are included (in x-y format), together with a two-parameter 'saturation growth' equation, enshrined in the French Specification: NF L 06-832, **y = a*x/(x+b)**. It can be seen that all four equations are reasonably good fits to the 'true shape'. The two-parameter exponential equation has a slight negative bias and the two-parameter growth rate equation has a slight positive bias – yielding saturation intensities of 0.00130 and 0.00126" respectively.

(c) Interaction between curve equation and data set characteristics

The next problem is to allow for the interaction between curve equation and data set characteristics. If a relatively low accuracy for the saturation point is acceptable then we can use the bare minimum of four points for the data set size. A four-point data set size prescribes the use of a two-parameter equation (such as h = a(1-exp(-b*t))). Greater accuracy will be achieved, for given data point variability, by using five-point data sets and a

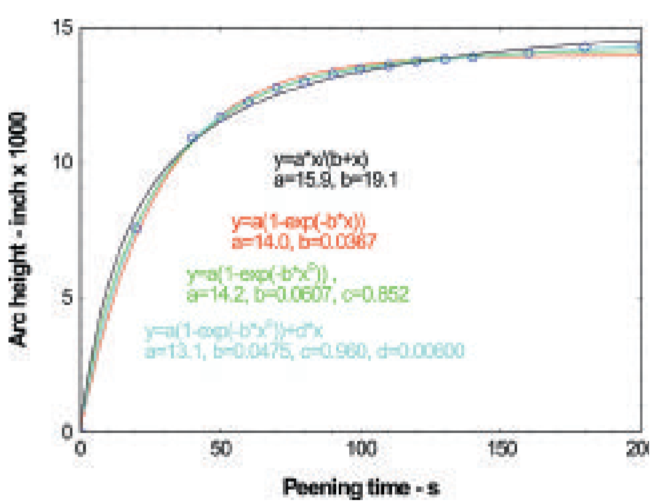


Fig.4 True shape data points fitted to a variety of equations.

Continued on page 30

Continued from page 28

three-parameter equation (such as h = a(1-exp(-b*t^c))). A six-point data set size will result in an even greater level of accuracy. The four-parameter equation, h = a(1-exp(-b*t^c)) +d*t, *can* be used with six-point data sets and might be expected to yield the most accurate result. In practice, however, three-parameter equations are more 'robust' and should normally be the preferred choice for six-point (or more) data sets.

(d) Accuracy of Curve Analysis Procedure

We do not need to be statisticians to appreciate the effects that our unavoidable arc height variability has had on our curve analysis. Visual examination of the plotted curve together with the data points will give us a *qualitative* impression of data set integrity. Computerized curve analysis allows *quantitative* impressions to be realized. Consider, for example, the results for the four-point SAE Data Set No. 6 shown in fig.5 and Table 5. Of the four points in the set the first two deviate substantially from the curve and the last two are very close to the curve.

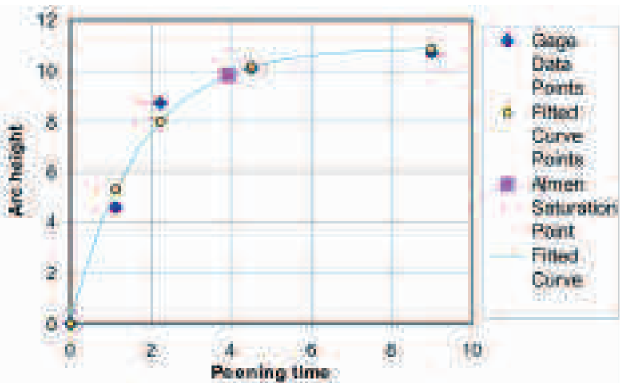


Fig.5 Two-parameter curve fitting of SAE Data Set No.6.

The curve fitting procedure used here is the "least-squares" method. This means that the 'MINSUM' of 0.99 in the last column of Table 5 is the smallest sum of differences-squared that can be found. Applying the same curve-fitting procedure to the six other four-point SAE data sets gives corresponding MINSUM values of 0.05, 0.09,0.05, 0.03,0.02 and 0.08. We can therefore equate the calculated MINSUM with the level of integrity for a given data set and hence question the integrity of set no.6 (MINSUM of 0.99). The "MINSUM" depends upon the number of points so that an alternative parameter, favored by statisticians, is the "RMS" as defined in Table 5.

Table 5 Values for two-exponent curve fitting of SAE Data Set No.6.

Strip No.	Time	Measured Arc Height	Curve point at same time	Difference	Difference -squared
1	1.13	4.6	5.28	+0.69	0.48
2	2.25	8.7	8.00	-0.70	0.49
3	4.5	10.1	10.13	+0.03	0.00
4	9	10.7	10.85	+0.15	0.02
[RMS is the "Root Mean Square" and is the square root of the average of the difference-squared values. Hence: RMS = SQRT(0.99/4)].					MINSUM = 0.99 RMS=0.498

DISCUSSION

All measurements have a degree of accuracy. That accuracy can be quantified in terms of precision and bias. The accuracy of saturation curve analysis depends primarily on two factors: data set characteristics (variability, number of points and peening time range) and curve equation. Increasing the number of data points offsets unavoidable variability of data. If the data set contains only four points then a two-parameter curve is appropriate but some bias of the analysis is unavoidable. With six points in a data set, bias is virtually eliminated - by being able to apply either a three- or four-parameter curve equation and by covering a wider time range. Data variability within the data set will also be indicated more clearly.

Almen arc height measurements are valuable pieces of information. Their value should not be diminished by subjective treatments such as manual saturation curve fitting. Computerized saturation curve analysis is a very simple operation and is completely objective. The computer program used should indicate which curve equation is being employed. Computed differences between data points and the fitted curve yield quantified measures of accuracy.

The value of Almen arc height data can be enhanced if it is computer-stored together with the computerized saturation curve analysis results and job setup details. A standard spreadsheet can accommodate all of the corresponding job setup details (shot type, machine type and number, machine settings etc.). We can then accumulate enough data to establish the standard deviations (of saturation intensity, saturation time, 'MINSUM' etc.) for each combination of job setup details. Then we can quantitatively assess the significance of subsequent 'unexpected results'. We could, for example, have a situation where a particular job setup was known to yield a saturation intensity of 0.0063" at 4.0 seconds with corresponding standard deviations of 0.0002" and 0.05 second. If, with the same job setup, the saturation intensity were subsequently found to become 0.00069" (three standard deviations away from the mean) at 4.0 seconds we would know that that was highly unlikely to be a purely random occurrence (Table 2 indicates a 'one in four hundred' possibility). Something has *probably* changed that has raised the 'indentation potential' of the shot stream – such as increased shot velocity or shot properties. Saturation times, though not substantially affecting saturation intensities, are useful indicators of shot flow rates and can be similarly analyzed. Machine controls have to be set in order to impose specified Almen intensities and coverages. Those controls have their own levels of accuracy. Peened strip arc heights can be used to assess the accuracy of each separate control. The accuracy of our saturation curves is a measure of our ability to control the relevant peening parameters.

CONCLUSIONS

1. The overall accuracy of a saturation curve analysis depends primarily on the number, range and accuracy of the arc height values in a given data set.
2. Computerized saturation curve analysis is more accurate than manual saturation curve fitting.
3. Arc height data should be fitted to an equation that reflects the 'true shape' of Almen saturation curves.
4. Computerized saturation curve analysis findings form a valuable control feature when used in association with job setup details.

Sonats: Past, present and future

by Jean-Michel Duchazeaubeneix

Sonats was founded in 1992 by Patrick Cheppe and Jean-Michel Duchazeaubeneix in Nantes on the west cost of France. The company presently employs 25 people. It was launched in the field of Stresses Characterization to optimize the process manufacturing and parts behavior by taking into account the residual stresses levels.

Sonats' portable StressVoyager® equipment is ideal for on-site repair applications.

Sonats proposed solution is to increase components' fatigue life with shot peening. In order to offer an innovative process, the company developed the ultrasonic process we named Stressonic®. The Stressonic® process is a surface treatment by impacts—throwing balls on a mechanical part. Balls are put in movement by metallic elements forming an acoustic block and vibrating with an ultrasonic frequency. This technology avoids losing balls during the treatment and allows the use of high quality bearing balls instead of conventional medias.

The target was, and is, to develop a global peening package from the understanding of the parts behavior like a medicine is a solution to the pharmacy. Depending on the application, Sonats proposes an evaluation of the best process to be applied on the part regarding the cost reduction and life enhancement goal. Then, after these validations by the engineers, Sonats is able to design and manufacture specific Stressonic® equipment, or propose a shop work or field job. The target is always to introduce compressive residual stresses for fatigue life enhancement or to be able to reduce the distortion after process manufacturing like machining, laser welding, etc.

The process is very repeatable because there are only three parameters to be controlled: Mass of balls, time and vibration amplitude of the sonotrode (continuously controlled during the treatment). The technology can also be used with WC (tungsten carbide) bearing balls, which are very expensive, but the process is very economical because only a few grams are used per batch. The reason to use WC balls is to avoid decontamination, especially on titanium parts, after peening with steel beads and then to increase the fatigue life. Also, WC balls, which have two times the steel density, allows the increase the surface compressive residual stress, then the fatigue life.

The equipment for Stresstronic® treatment on blades.

These previous concepts are used for shot peening and peen forming, but to reduce the distortion after manufacturing, it is necessary to have a powerful portable unit with no risk of loose medias during the treatment. Sonats developed a specific head with projectiles named Spherils®—they look like pins or needles— that stay inside the chamber and have a mass between 10 to 50 times a 3 mm bearing balls.

Our portable equipment, StressVoyager®, can be used manually for this repair with high power and speed and no loss of media.

Now Sonats is marketing its technology and package worldwide. Our core business is Aerospace, Power Generation (nuclear, gas turbine, hydro), and Automotive. We are developing our presence in industrialized countries: West and North Europe, Japan and North America. Today, Sonats' worldwide presence for technical development, sales and technical assistance covers all industrialized countries. This world presence was initiated six years ago with Japan, and the major growth was initiated between 2003 and 2004. Since 1997, Sonats has been developing relationships directly with the customer. 2005 was the year of international consolidation and development in sales and technical agreement. In the future, subsidiaries or joint ventures will most likely be established in North America, Japan and Germany.

Sonats wants to develop Aerospace and Energy value-added products that require the Sonats competencies that take into account residual stresses and material behavior, and require a surface treatment like Stressonic®. This is why we created the Europe Technologies company five years ago. Through this company, we bought three mechanical companies in France. We created a design department, and we developed products for Aerospace and Energy like the riveting process and portable automatic drilling unit. First, we want to develop the components and products for the French market and then expand these products through Sonats International.

For more information on Sonats, please visit our web site at www.sonats.com or contact us by telephone: 033-251-700-494 or e-mail: sonats@sonats.com.

Troubleshooting your shot peening operation

by Herb Tobben

While shot peening is a highly technical and complex process, governed by societies and panels of experts, it can be, but need not be, intimidating. Because of the many variables that affect shot peening results, standards help to ensure consistent quality of output. Understanding the variables and how they impact the results simplifies the process and can make troubleshooting easier.

Most standard specifications are patterned after military or SAE engineering specifications. And it's important to understand that many manufacturers set their own process standards, either to cover shot peening in their plants or to set standards for their vendors. Critical-application shot peening, such as is done on aircraft and aerospace components, will have a set of specifications to follow. These specs provide a wealth of information and a rigid framework of guidelines to follow. The specifications will either reference the standard SAE specification or in some cases, the manufacturer will create their own specifications that incorporate the SAE spec and either add to or over-ride part of the SAE specification.

Since these specs are guidelines for intensity and coverage that must be achieved as well as the media and the size to use on your particular substrate material, it is up to you to determine how to combine the many variables. These variables include media size and hardness, nozzle size, distance, angle, and pressure; as well as how long to peen and what shot flow rate will be necessary to achieve the desired result. The manufacturer's print of the part will call out the intensity needed as well as the shot size to use and the coverage to be achieved.

When initially setting up your shot peening operation or when failures occur, here are some suggestions for determining what's going wrong and how to obtain the results you seek.

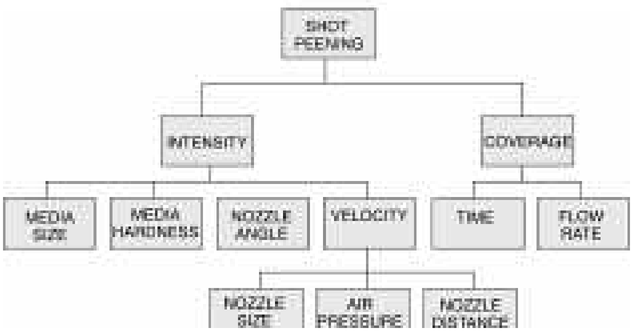
Intensity
With the intensity given on the print, the challenge is to maintain consistent conditions to obtain consistent results over the production run. When intensity is not being maintained, the variables that affect it include: media size, media hardness, blasting angle, and blasting velocity. I usually begin with the variables that are the easiest to check and work my way to the more complicated ones.

Media Size
This sounds like a no brainer; but check the working mix— it may not be right. Of course, you may have the wrong media size—someone may have ordered the wrong size. Mix-ups can also happen when there are several shot peening operations each using different media.

Media Hardness
The media must always be harder than the part. Check to make sure the media hardness is correct. Shot varies in hardness and is measured on the Rockwell scale. Soft shot measures between 40 and 45 Rc; but it is available up to a 62 Rc. Hardness ranges will vary by media manufacturer.

Blasting Angle
Verify that the angle of impingement is correct. Your records will state what the angle should be. Vibration in the system can cause nozzle movement; changing the nozzles can also cause the angle to be inadvertently altered.

Blast Velocity
When blasting velocity is not being maintained, the nozzle size, air pressure, and distance from the work piece may need to be modified. Measuring blast velocity is a more complex process; so



I leave that until the other variables have been verified. Check the air to media ratio (the shot flow rate). There are numerous ways to check the blast velocity—the easiest being using an electronic instrument pointed toward the blast stream during operation.

Nozzle Size
Check the nozzle to determine if it has worn out and needs to be replaced. Check to make sure the nozzle has not suffered some kind of damage. It may have become scored or become damaged in some way.

Air Pressure
Make sure you can maintain air pressure when all the nozzles are on. Sometimes the systems get overloaded when greater demand is generated than the source is capable of providing. Make sure the air line diameter is appropriately sized.

Distance
Measure the distance from the nozzle to the work surface. Just as some of the other variables accidentally can be altered, so can the distance. Compare your measurement with your set up documentation.

Coverage
If coverage is not being achieved, blast time and media flow rate need to be checked and adjusted as necessary.

Blast Time
Check the time of the blast cycle. Someone may have changed the setting; or the timer could be defective.

Media Flow Rate
Check the metering valve for signs of tampering, or for wear. Check to make sure there are no foreign materials in the metering valve, hose, or nozzle. Replace components as needed.

Recordkeeping is perhaps drudgery, because it is a requirement. It's as much fun as reading an owner's manual; but it is indeed your friend. Making simple checks of the system and consulting your notes can save hours of frustration since with shot peening you are always working with so many variables. Of course, I hope you know that when you're stumped, you can always call me. (1-636-239-0300)

Herb Tobben, the Sample Processing Manager of the Technical Services Department for Zero Cabinets and Zero Automation at Clemco Industries, creates solutions to customer problems.

2005 Shot Peeners of the Year

Congratulations to **Marsha Tufft** and **Helmut Wohlfahrt**, our 2005 Shot Peeners of the Year. Ms. Tufft was chosen in honor of the thesis she authored while working at GE. It is a very comprehensive investigation of effects and influences of shot peening titled: Development of a Fracture Mechanics/Threshold Behaviour Model to Assess the Effects of Competing Mechanisms Induced by Shot Peening on Cyclic Life of a Nickel-base Superalloy, Rene 88Dt. Prof. Dr. Wohlfahrt is a member of the International Scientific Committee on Shot Peening and has been a driving force in coordinating and guiding the growth of the triennial International Conferences on Shot Peening. The following biographies will highlight the achievements of these important contributors to both the scientific and industrial components of shot peening.

Marsha Tufft graduated with a B.S. in Mechanical Engineering from Purdue University in 1981. She joined GE Aircraft Engines in Cincinnati, Ohio in their Engineering Development Program where she earned her M.S. in Aerospace Engineering from the University of Cincinnati in 1984. At GEAE, she has worked in Commercial, Military and Marine & Industrial Life Management groups as well as Life Methods. It was while working in the CFM56 Life Management group in 1984 that she was first exposed to the shot peening process, and this experience later contributed to her choice of shot peening as the focus of her PhD dissertation. While working in Life Methods, she earned her PhD in Materials Engineering from the University of Dayton in 1997. Her dissertation, "Development of a Fracture Mechanics/Threshold Behavior Model to Assess the Effects of Competing Mechanisms Induced by Shot Peening on Cyclic Life of a Nickel-base Superalloy, Rene' 88DT" focused on understanding and predicting the onset of peening damage, as well as the resulting life impact. During this time, Ms. Tufft gained a strong appreciation for the need for improved process control and greater rigor in establishing Almen intensity by regression analysis of saturation curve data, and the inherent difficulties of establishing a robust definition for 100% coverage. Her work also identified a clear value for velocity measurements for process control. Her current interest is in better understanding the mechanisms that result in fatigue life benefit, as well as the effect of thermal exposure and cyclic loading on life capability, the effect of re-peening after cyclic usage, as well as championing more precise/robust documentation of shot peening conditions, particularly in technical literature.

Prof. Dr. -Ing. Helmut Wohlfahrt began his college education in 1955 as student of Mechanical Engineering at the Technische Hochschule Stuttgart. He completed his Diploma thesis at the well-known Max-Planck-Institute for Materials Research in Stuttgart. The diploma thesis led Prof. Dr. Wohlfahrt in the direction of materials science. Proceeding in this direction, he gathered experience on heat treatment techniques for metals at an institute in Bremen (1964-1966) and changed in 1966 to the Institute for materials science and engineering at the University of Karlsruhe.

In 1966-1979, Prof. Dr. Wohlfahrt was a Scientific Assistant at the Institute for materials science and engineering at the University of Karlsruhe. He completed his doctoral thesis at this institute under the leadership of Prof. Dr. E. Macherauch. He investigated the influence of residual stresses due to different heat treatments on the fatigue behaviour of steels and continued with research projects on the effects of residual stresses due to machining and eventually also due to shot peening.

Since 1979, Prof. Dr. Wohlfahrt has been the Professor and Chair of materials technology and welding techniques at the University of Kassel. The main theme of research topics during his time in Kassel was "techniques for fatigue strength improvement of metals, structural components and welded joints" including heat treatments, machining, modern welding technologies and especially shot peening.

As a consequence of his shot peening research, Prof. Dr. Wohlfahrt got in contact with the international shot peening community by attending the first meeting Dr. Niku-Lari organized in Las Vegas in 1980. Prof. Dr. Wohlfahrt became a member of the International Scientific Committee on Shot Peening and participated in the 1st International Conference on Shot Peening 1981 in Paris, and with one exception, participated in all following conferences. During the Shot Peening Conference in Chicago in 1984, he became the Chairman of the International Scientific Committee on Shot Peening and initiated the formation of a German technical committee on "Material's Treatment by Shot Peening" together with the DGM (Deutsche Gesellschaft für Metallkunde). This committee was the basis for organizing the 3rd International Conference on Shot Peening in Garmisch-Partenkirchen/Germany in 1987, which he chaired.

Since 1991, Prof. Dr. Wohlfahrt has been the Professor and Chair of welding techniques at the Welding Institute of the Technical University of Braunschweig. The research activities in this position have been extended to a number of welding specific themes, but the significance of shot peening for welded joints and structures was still a matter of research projects. The total number of his publications increased to more than 300 during this time.

In October 2002, his successor took over the Chair at the institute in Braunschweig. Prof. Dr. Wohlfahrt now lives as a pensioner near Karlsruhe at the north end of the Black Forrest. He enjoys traveling and is still active with tasks in connection with shot peening courses and also in the German Welding Society and in the International Institute of Welding (IIW), from which he received the Arthur Smith Award last year.

Marcel van Wonderen accepts award for Best Research Paper at WJTA Conference

Marcel van Wonderen, KLM and Lydia Frenzel, director of the WJTA Advisory Council and an expert in surface preparation and waterjetting.

Amsterdam, Netherlands. Marcel van Wonderen, Master Engineer Process, Equipment & Materials Development for KLM, Amsterdam, Netherlands, accepted the Best Research Paper award at the 2005 WJTA Conference. The paper was entitled, "Controlled HVOF Hard Coatings Removal Method," and was written by Kimmo Ruusuvuori, Kari Lahdenperä, Maria Oksa Erja Turunen, Juha Kauppila and Marcel van Wonderen.

The WaterJet Technology Association is international in scope with corporate and individual members throughout the world. Membership is comprised of waterjet users, manufacturers, distributors, researchers, regulators, and consultants.The primary goals of the association include enhancing communication within the industry; facilitating cooperation between government, industry, university and research institutions; fostering foreign and domestic trade in jet cutting and cleaning products and services; and studying and advancing the arts and sciences of jet cutting of industrial and geological materials, as well as industrial cleaning.

In memory of Dean Davis

Dean Davies, Sales Manager with Ervin Industries, passed away on November 6, 2005, after a long and courageous battle with cancer. Dean started with Ervin in 1976 making Amasteel abrasives at the Adrian, Michigan plant. In 1992, he was promoted to Sales Manager and he enjoyed the hands-on experiences of helping customers solve problems or improve operations. "He was quick to laugh, first to help out, and enjoyed his many friends," said Bill Rhodaberger with Ervin. Everyone that knew Dean would agree and he will be deeply missed.

Peening Technologies of Georgia earns FAA approval

Austell, Georgia. Peening Technologies of Georgia, a Hydro-Honing Laboratories, Inc. company, has earned its FAA approval. They are FAA Repair Station #G89R878X.

Peening Technologies of Georgia is now qualified for limited specialized services dealing with shot peening and abrasive blasting which require FAA approval. The company is also Nadcap accredited.

Peening Technologies of Georgia (formerly T&S Metal Finishing) was established in 2003 and is the newest division of Hydro-Honing Laboratories, Inc. Hydro-Honing was founded in 1966 and currently does business in East Hartford, Connecticut as Peening Technologies of Connecticut. With locations in Connecticut and Georgia, the company specializes in shot peening services for parts ranging from simple springs to complex parts for NASA's space shuttle. Peening Technologies also performs peening on airframes and helicopter and turbine engine components as well as non-aerospace parts including deep hole drilling equipment and automotive parts. For more information, visit their web site at www.peeningtechnologies.com.

New Peenscan pens from Electronics Inc.

Mishawaka, Indiana. Electronics Inc. introduced the new Peenscan pens at the 2005 Shot Peening and Blast Cleaning workshop. The pens are manufactured by Metal Improvement Company and will be distributed by Electronics Inc.

The new pens make the Peenscan process as easy as using a magic marker. The Peenscan 220-2 pen should be used for softer base metals, softer shot and lower peening intensities. The 220-6 pen should be used for harder base metals, harder shot and higher peening intensities. For example: When peening 304 S/S at an intensity of 6a to 9C with 110 shot, one should use the Peenscan 220-2 pen. When peening 4340 steel at a 6A to 16A intensity with 110 hard shot, use the Peenscan 220-6 pen.

The Peenscan process is a method used to measure the amount and uniformity of "coverage" obtained during automatic, semi-automatic or manual shot peening of metal parts. The objective of the Peenscan process is to provide a practical way to measure coverage in terms of amount and uniformity via monitoring of the degree of removal of a fluorescent tracer dye, which is applied to the work piece. The Peenscan pens use specialty formulated tracer dye liquids known as Dyescan fluids. The choice of an appropriate Dyescan fluid is dependent on the hardness of the metal and the intensity of the shot peening process. The Peenscan process facilitates quality control of the shot peening process.

The residual Dyescan, which remains on a part after shot peening, will identify flat spots and incomplete peening of surfaces. The uniformity of the Dyescan liquid viewed under UV light after the shot peening process will give some evidence as to the degree of removal, or percentage of coverage that has been applied to the different part areas. It is possible to develop visual calibration standards for Dyescan coated coupons that have been exposed to various degrees of shot peening coverage.

For more information on the pens or other our coverage products, call EI at 1-574-256-5001 or 1-800-832-5653.

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The Parting Shot
Jack Champaigne

2005 U.S. Workshop

Electronics Inc. is proud to be the first organizer of shot peening workshops worldwide. Since 1991 when the first Shot Peening workshop was held in Atlanta, Georgia, it has been our concept to bring industry leaders together to educate students as well as each other on not only the fundamentals of shot peening and blast cleaning but the current trends and changing technology.

Fifteen years later, the original concept stands true today more than ever. At this years workshop in Fort Worth, Texas, we had 60 first year students of which 40 took the level one exam. Additionally, we had attendees who returned this year, as every year, just to keep abreast of the industry. Each attendee designed his/her own curriculum from four classrooms that covered 47 different topics with 29 instructors. Between classes, attendees had an opportunity to discuss issues one-on-one with instructors, each other and with the show exhibitors.

Kumar Balan's article on page 20 re-caps his workshop class on machinery as it applies to designing equipment to meet audit requirements (notably Nadcap). His material was of interest to many attendees, even if Nadcap accrediation was not necessary to their organization since all aspects of controlling the process are critical to improving quality, while reducing costs. This starts with specifications and criteria as it applies to a given part design requirement. In this case, Mr. Balan highlights the need to meet Nadcap audits (see article on page 20) with machine design criteria.

In the end, this workshop was a huge success. First year year students as well as seasoned attendees were able to continue to learn more about the industry and the new trends that will strengthen the process. I would like to thank all the instructors, attendees and friends who contributed to make this workshop an opportunity for everyone to learn, as I do, at every workshop.