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.

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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

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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

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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

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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

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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.