ICSP15

15th International Conference on Shot Peening

PROGRAM & ABSTRACTS

September 22 - 25th, 2025

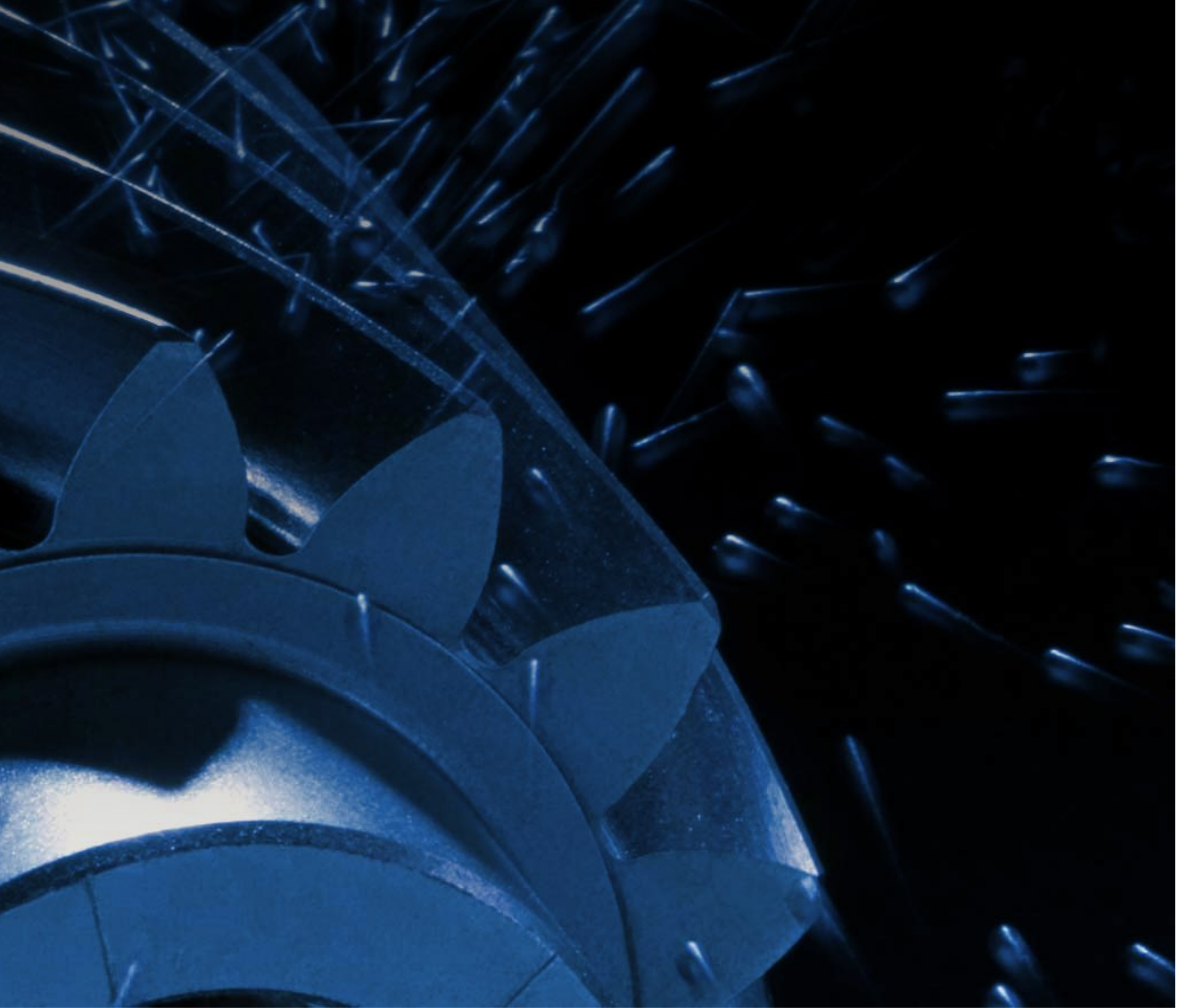
CSEE
Center for Surface Engineering and Enhancement

PURDUE UNIVERSITY | School of Materials Engineering

ICSP15

15th International Conference on Shot Peening

Purdue University, September 22nd—25th, 2025



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Professor David Bahr

Senior Associate Dean for Faculty, College of Engineering
Professor of Materials Engineering,
Conference Chairman, ICSP15 & Vice-Chairman, International Scientific Committee for Shot Peening

Welcome to ICSP15 and Purdue University!

Every three years (or so) the shot peening community gathers to share advances in peening technologies. From topics as broad as advanced modeling of processing to experimental evidence of the changes in surface stresses and microstructures, researchers and practitioners bring new results to continue to advance the field. The presentations and papers you'll see this week are the field's way to share new results, to stimulate new ideas, and to document the changes in our understanding of the processing and behavior of a critical tool in improving materials performance.

Science and engineering as a field moves forward by the open exchange of ideas. We tell each other our recent successes, we share our challenges, and we explain our failures in the hope of better understanding complex physical phenomena. The International Scientific Committee for Shot Peening, under who's auspices this meeting runs, is a wonderful example of world-wide cooperation in science. Conferences like this exist to serve a need for the formal exchange of information but also the interaction with people who do the work. We could all write papers, read those papers, and independently glean new ideas in how to improve what we're working without talking to one another face-to-face. But conferences bring something special, the personal interaction with professionals allows us to discuss a problem, to share a story, and spark a new idea with a colleague. We need colleagues that collaborate and a community that supports one another, even while competing in business, to find solutions that improve engineering materials and serve our customers better.

And conferences provide an outstanding opportunity for experts share experiences with new participants in the field.

The School of Materials Engineering at Purdue University and the Center for Surface Engineering Enhancement is proud to welcome you to this 15th formal exchange of ideas in advancing peening technologies. The scientific meeting format provides an experience that, to paraphrase one of Purdue's most well-known graduates, help us take those bigger leaps as a group, going further than we could just making our own small steps. I hope that if you've been here from the beginning, you get a chance to catch up with the colleagues you know. I hope that if this is your first ICSP you get a chance to meet others that share your interest in making better materials through surface processing. And I hope you all have that moment where you get a scientific spark; where the new idea pops out because you just saw a research show a new technique, met a vendor offering a new tool, and you realize "hey, if I tried that, I think we'd be able to….". I don't know what that idea is for you, but I know that meetings like this are a great way to find those new ideas that help advance our field.

Have a great conference,

David Bahr

(Chair, ICSP15)

ICSP 15 Committees

International Scientific Committee for Shot Peening

Mario Guagliano (Italy) – President
David Bahr (Vice President)
Jack Champaigne (USA)
Seong Kyun Cheong (Korea)
Hali Diep (USA)
Bernd Eigenmann (Germany)
Sylvain A. Forgues (Canada)
Jia-Wen He (China)
Michael R. Hill (USA)
Chuanhai Jiang (China)
David Kirk (UK) – Honorary Life Member
Yuji Kobayashi (Japan)
Andrew Levers (UK)
Eckehard Müller (Germany)
Abbas Niku-Lari (France) – Honorary Life Member
Holger Polanetzki (Germany)
Paul Prevey (USA)
Mamidala Ramulu (USA)
Delphine Retraint (France)
Volker Schulze (Germany)
Koji Takahashi (Japan)
Lothar Wagner (Germany)
Yoshihiro Watanabe (Japan)
Kewei Xu (China)
Yuji Sano (Japan)

ICSP15 Local Organizing Committee

Jennifer Brown – American Axle Manufacturing
Mike Schmidt – General Electric Aerospace
Steve Ferdon – Cummins
Jim Whalen – Progressive Surface
Michael Halsband – Sinto America
Kumar Balan – Ervin Industries
Shota Watanabe – Toyo Seiko

ICSP Conference Contacts

David Johnson — Conference Vice Chairman | davidjoh@purdue.edu
Mark Gruninger — Conference Vice Chairman | mgruninger@purdue.edu
Maddison Walsh — Lead Admin | mhoverm@purdue.edu

Purdue University

Purdue University

Located in West Lafayette, Indiana, Purdue University is a world-renowned public research institution recognized for its academic excellence, innovation, and impact. Founded in 1869, Purdue serves more than 50,000 students and is consistently ranked among the top public universities in the United States. Its commitment to discovery and practical solutions has made Purdue a global leader in higher education, particularly in science, engineering, and technology.

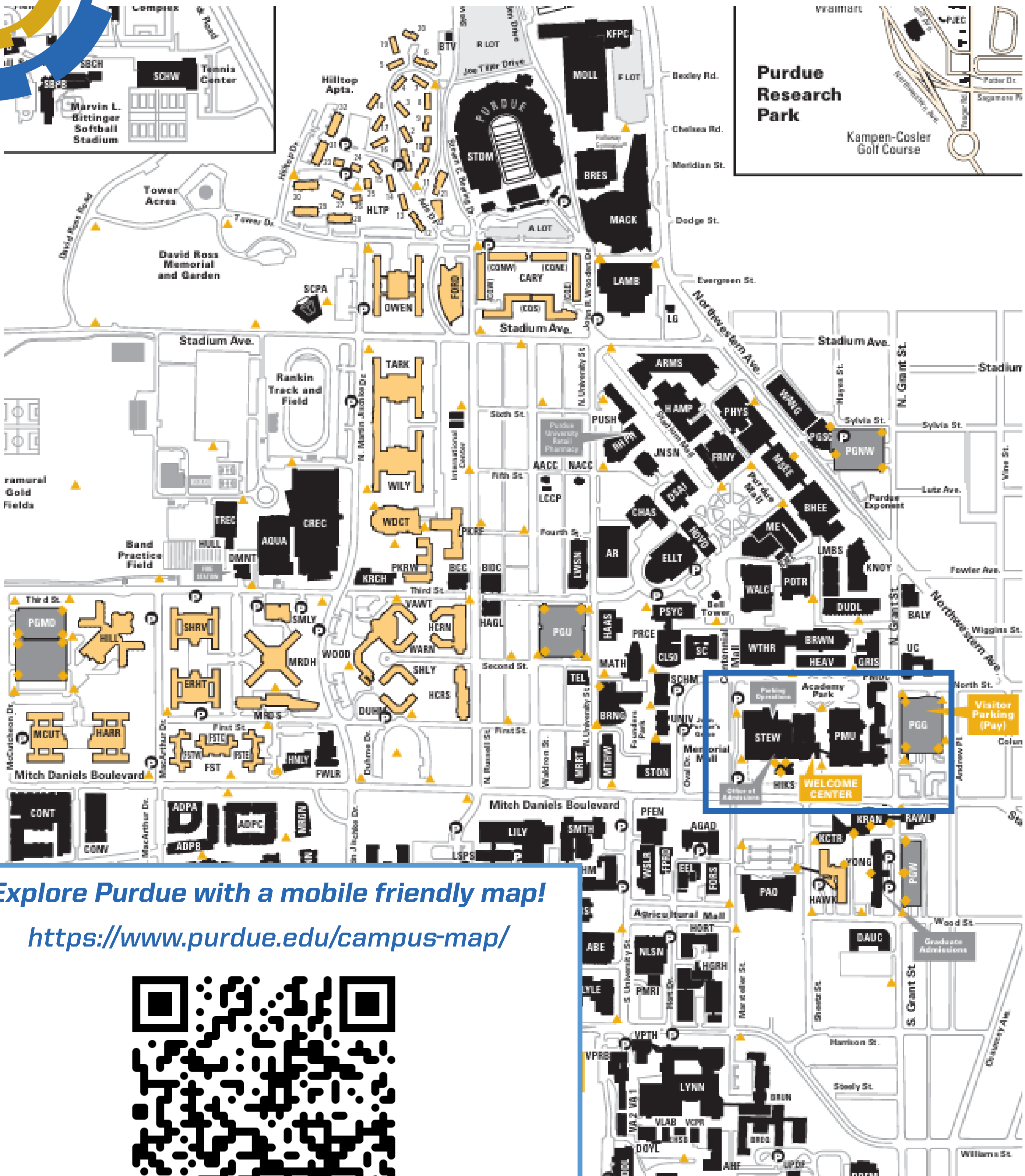
College of Engineering

The Purdue College of Engineering is one of the largest and most prestigious engineering programs in the United States. Home to more than 14,000 students and 600+ faculty, the college consistently ranks among the top ten nationally. With over 14,000 students and a distinguished faculty, the college is ranked among the top 10 engineering programs in the U.S. It is known for its strong industry partnerships, interdisciplinary research, and commitment to solving complex global challenges. Purdue Engineering graduates are widely recognized for their technical expertise, leadership, and innovation.

School of Materials Engineering

A core part of Purdue's engineering legacy, the School of Materials Engineering (MSE) combines scientific fundamentals with real-world application. Established in 1959, MSE leads research and education in metals, polymers, ceramics, composites, and emerging materials. Its faculty and students work closely with industry and government agencies on projects with direct societal and industrial impact. The school is internationally recognized for its contributions to advanced manufacturing, sustainable materials, and next-generation technologies.

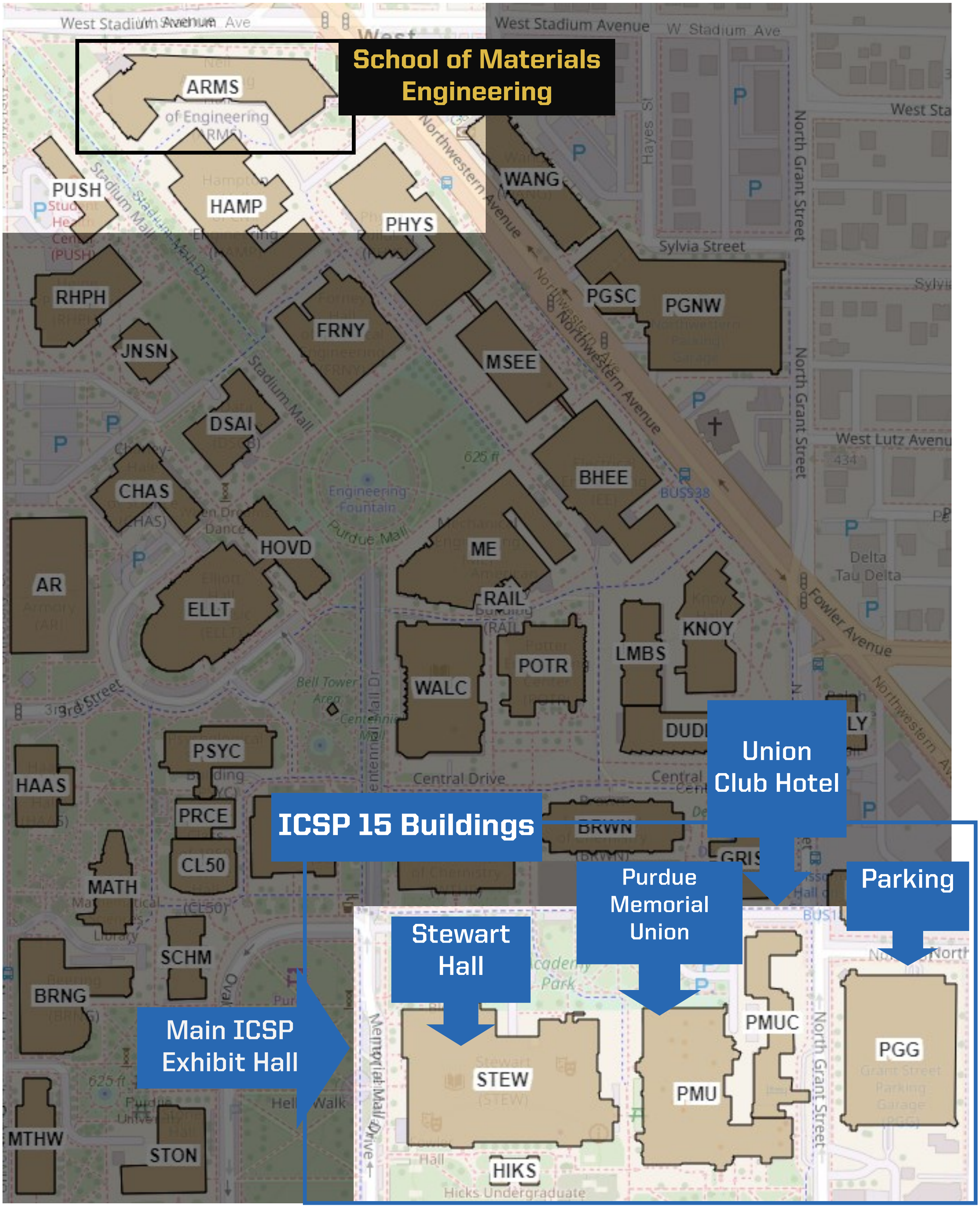
Purdue Campus



Explore Purdue with a mobile friendly map!

https://www.purdue.edu/campus-map/

ICSP at Purdue



Airport Access

Getting to Purdue: Nearby Airports

Whether you're traveling internationally or domestically, several airport options make getting to Purdue University convenient and accessible for ICSP15 attendees:

Indianapolis International Airport (IND)

Located approximately 70 miles (110 km) south of West Lafayette, IND is the most commonly used airport for visitors to Purdue. It offers frequent domestic and international flights and is about a 1.5-hour drive to campus. Rental cars, rideshares, and scheduled shuttle services are widely available.

Chicago O'Hare International Airport (ORD)

As one of the busiest international airports in the world, O'Hare (ORD) provides extensive global and domestic connections. It is roughly 140 miles (225 km) from Purdue University, with a travel time of about 2.5 to 3 hours by car. Several shuttle and train options are available, especially for international travelers connecting through Chicago.

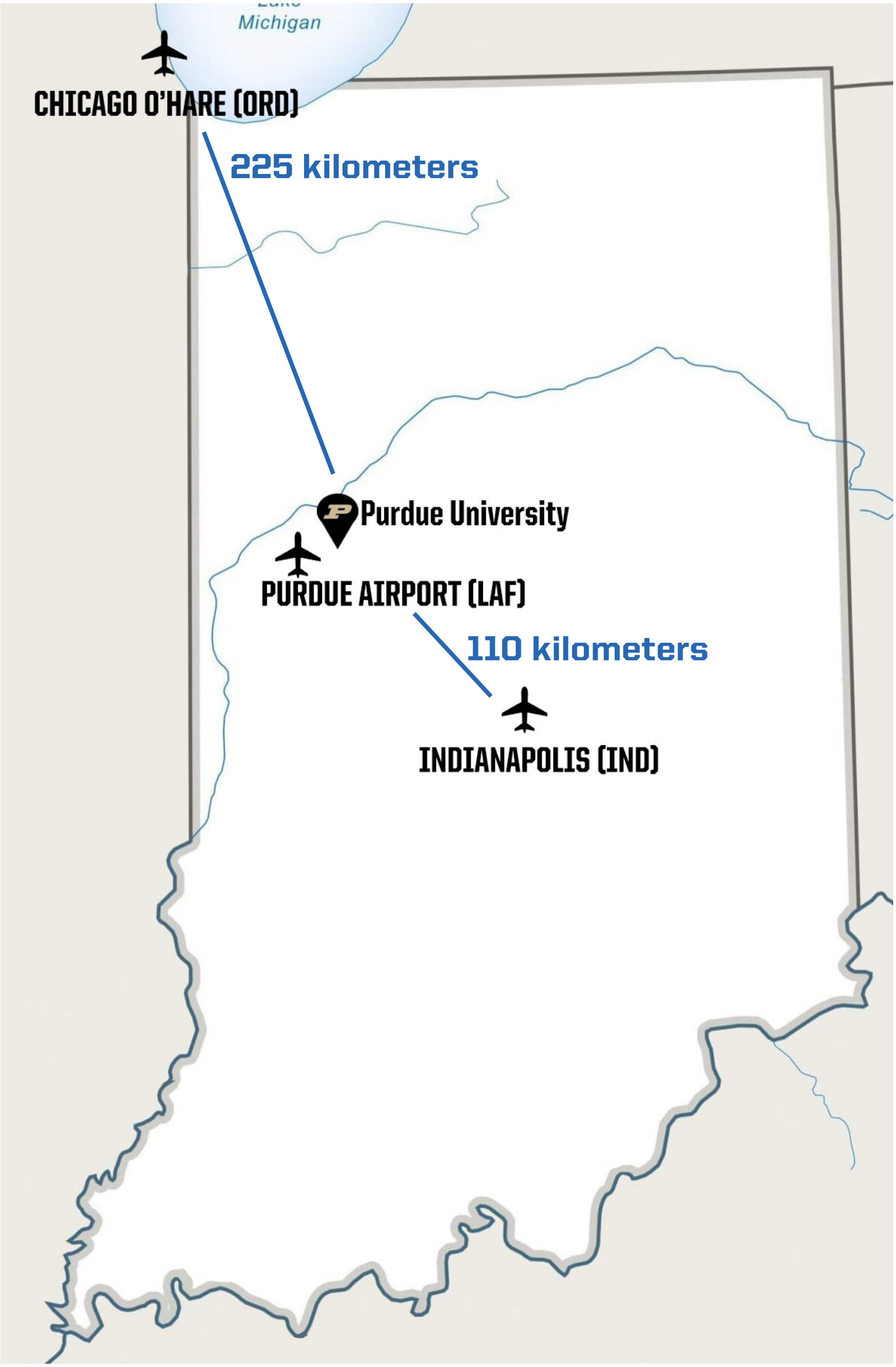
Purdue University Airport (LAF)

Conveniently located adjacent to Purdue's campus, the Purdue University Airport (LAF) now offers scheduled commercial service for the first time in years.

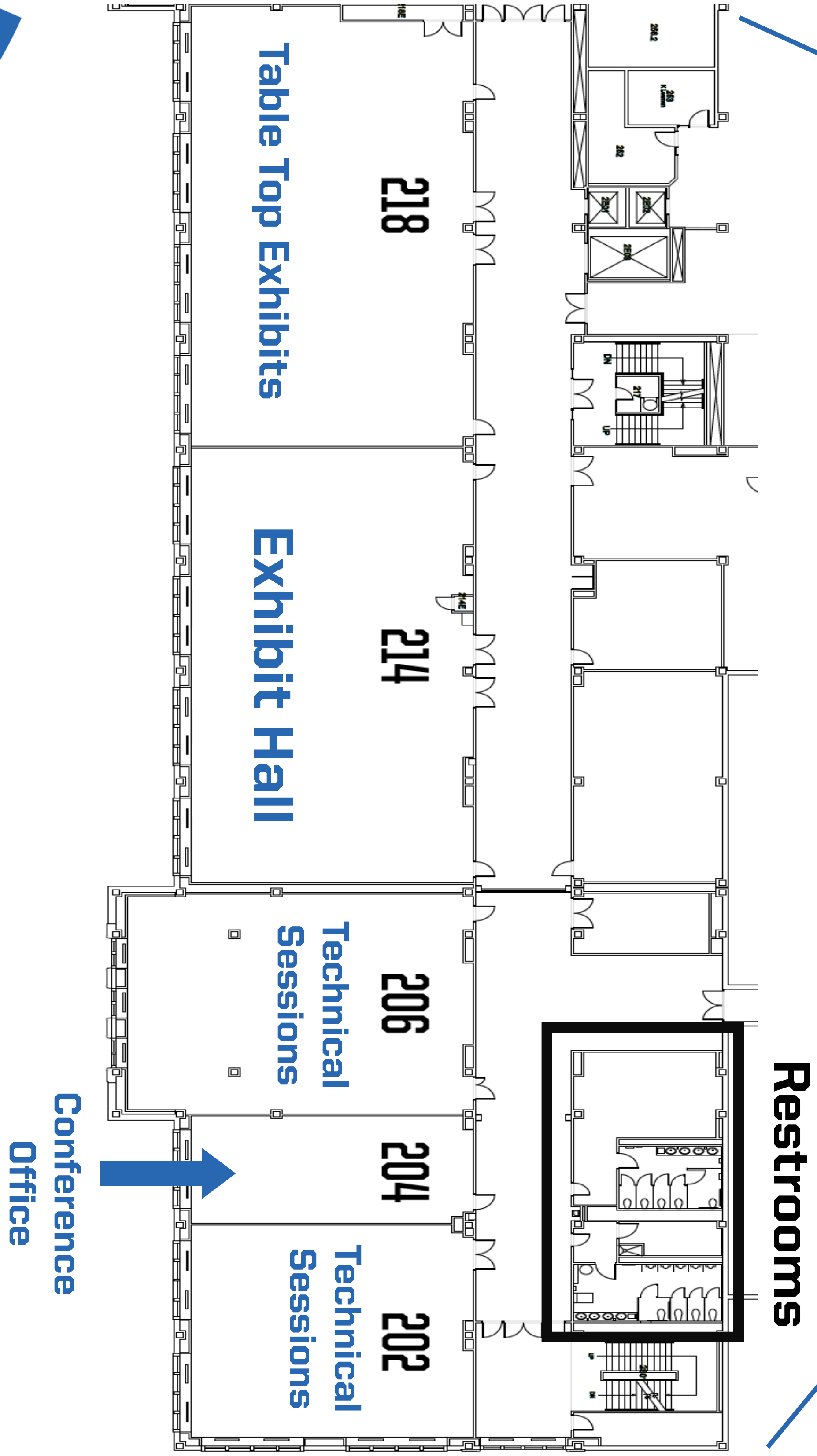
- Southern Airways Express operates daily flights between LAF and Chicago O'Hare (ORD) using Cessna Caravan aircraft.

- Beginning August 5, 2025, United Express (operated by SkyWest Airlines) will launch jet service from LAF to ORD using CRJ-200 aircraft, providing expanded options and increased comfort.

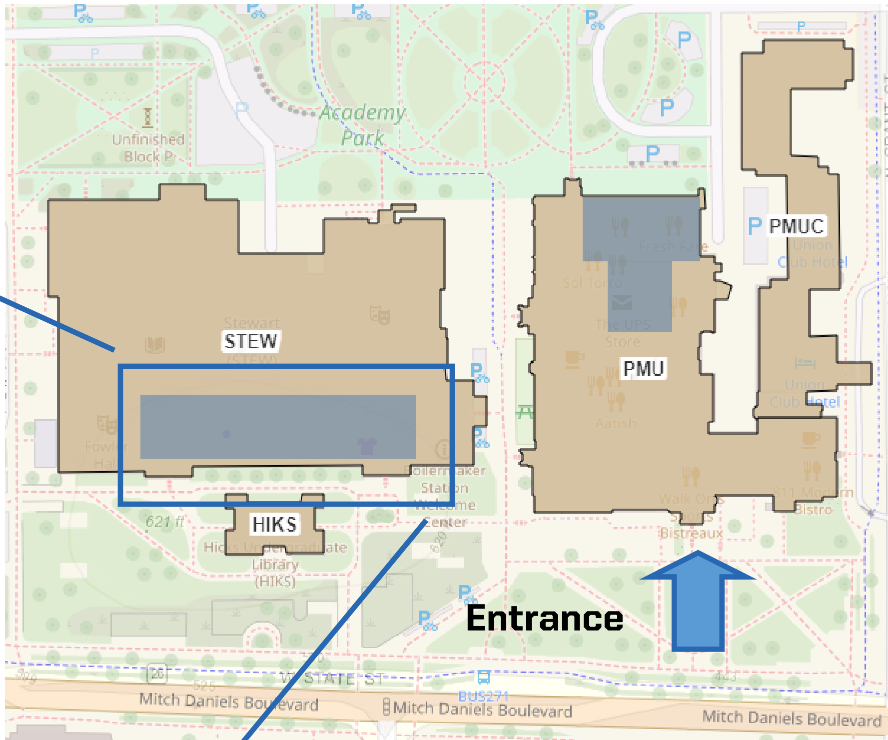
While LAF is still limited in terms of destinations, these connections to O'Hare allow for seamless national and international travel—all within minutes of campus.

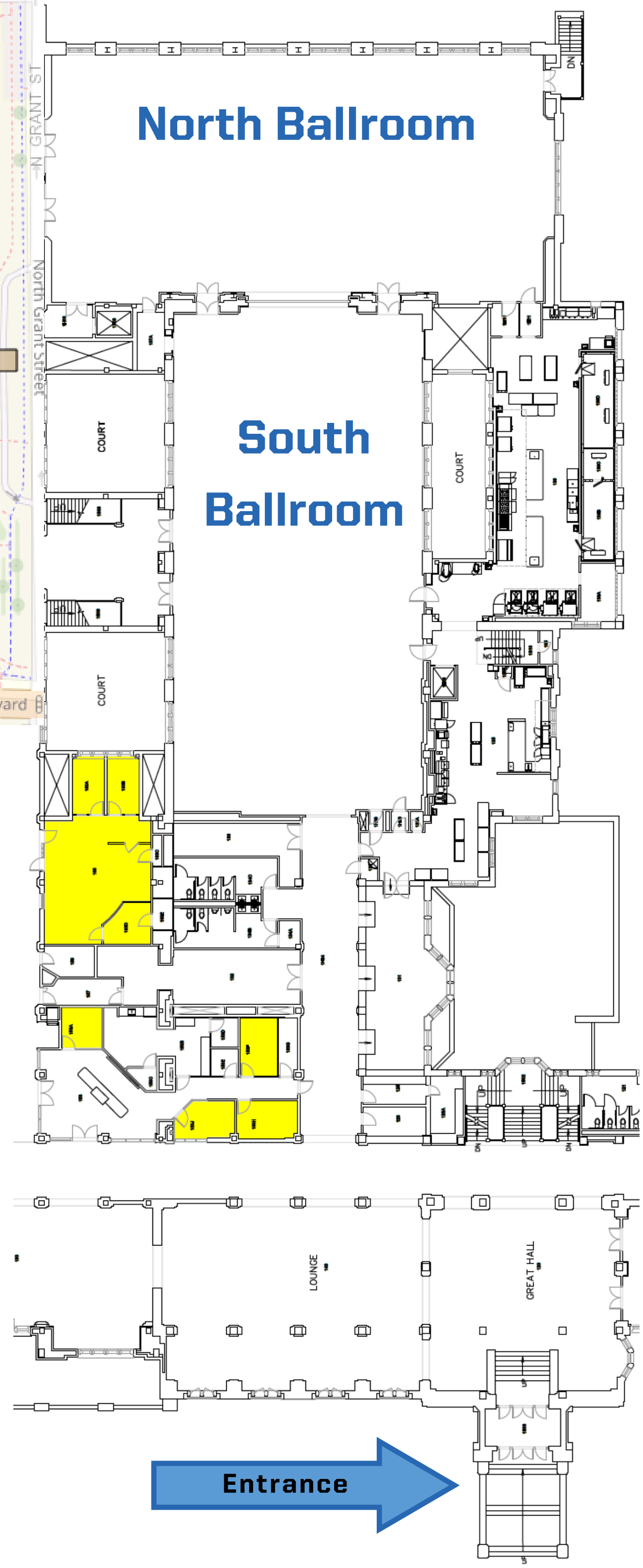

Lake Michigan
CHICAGO O'HARE (ORD)
225 kilometers
Purdue University
PURDUE AIRPORT (LAF)
110 kilometers
INDIANAPOLIS (IND)

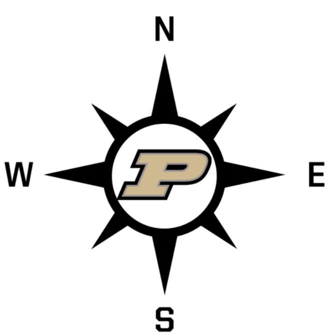
Stewart Hall Map



Purdue Memorial Union Map







15th International Conference of Shot Peening Agenda

Monday | 09/22

Time	Event	Location
1:00 – 3:00 PM	**Exhibitor Check-In**	PMU South Ballroom
1:00 – 5:00 PM	**Exhibitor Set-up**	STEW 214
3:15 – 6:30 PM	**Registration Check in**	PMU South Ballroom
5:30 – 7:30 PM	**ICSP Opening Reception**	PMU South Ballroom

Tuesday | 09/23

Time	Event	Location
8:45 – 9:00 AM	**Welcome – Dave Bahr (ICSP15 Chairman)**	PMU North Ballroom
9:00 – 9:15 AM	**Jack Champaigne – Honoring Professor Kirk**	PMU North Ballroom
9:15 – 9:45 AM	**Plenary Session – Mario Guagliano** *"From Shot Peening of Historical Pompeii Walls to the Redesign of Roman War Machines: A Reverse Engineering Approach"*	PMU North Ballroom
10:00 – 10:30 AM	**Coffee Break in Exhibit Hall**	STEW 214
10:45 – 12:05 PM	**Technical Sessions** • Industrial Applications 1 • Surface Engineering 1	STEW 202, 206
12:15 – 1:15 PM	**Lunch**	PMU South Ballroom
1:25 – 2:45 PM	**Technical Sessions** • Industrial Applications 2 • Surface Engineering 2	STEW 202, 206
2:45 – 3:15 PM	**Coffee Break in Exhibit Hall**	STEW 214
3:30 – 6:00 PM	**Center for Surface Engineering Tour (CSEE) & Demos**	2550 Northwestern
7:00 – 9:00 PM	**Conference Dinner**	PMU South Ballroom

Wednesday | 09/24

Time	Event	Location
8:30 – 9:50 AM	**Technical Sessions** • Residual Stress • Laser & Alternative Peening 1	STEW 202, 206
10:00 – 10:30 AM	**Coffee Break in Exhibit Hall**	STEW 214
10:30 – 11:30 AM	**Technical Sessions** • Shot Peening of Additive Materials 1 • Laser & Alternative Peening 2	STEW 202, 206
11:45 – 12:45 PM	**Lunch (Speaker: Cory Padfield)**	PMU South Ballroom
12:45 – 2:30 PM	**Bus Loading & Travel to IMS Museum**	Memorial Mall
2:45 – 4:45 PM	**Visit Indianapolis Motor Speedway Museum**	IMS Museum
4:45 – 6:30 PM	**Travel Back to Purdue**	
7:00 – 9:00 PM	**Exhibitor/Sponsor Dinner**	John Purdue Club

Thursday | 09/25

Time	Event	Location
8:30 – 9:50 AM	**Technical Sessions** • Fatigue 1 • Industrial Applications 3	STEW 202, 206
10:00 – 10:30 AM	**Coffee Break in Exhibit Hall**	STEW 214
10:45 – 11:45 AM	**Technical Sessions** • Shot Peening of Additive Materials 2 • Fatigue 2	STEW 202, 206
12:00 – 1:00 PM	**Lunch & Posters**	PMU South Ballroom
1:10 – 2:30 PM	**Technical Sessions** • Industrial Applications 4 • Innovative Shot Peened Steel Dynamics	STEW 202, 206
2:30 – 3:00 PM	**Coffee Break in Exhibit Hall**	STEW 214
3:15 – 4:30 PM	**ISCSP Meeting**	STEW 202
	Industrial Modeling of Shot Peening	STEW 206

Jack Champaigne

President of Electronics Inc
Member of the International Scientific Committee for Shot Peening
Chairman of the SAE Committee on Shot Peening
Distinguished Engineering Alum of Purdue University

Biography: Jack Champaigne has dedicated his career to the relatively unheralded field of shot peening. Champaigne, who obtained a bachelor's degree in electrical engineering in 1968, carved a career path marked by innovation and know-how in surface enhancement engineering. Following six years in the aerospace industry, he ventured into entrepreneurship and founded Electronics Incorporated (EI) in 1974. The company swiftly rose to prominence, becoming a global authority on fatigue and stress analysis, particularly in surface enhancement engineering.

In the 50 years that followed, Champaigne gained a thorough understanding of the history, theory, specifications and practical applications of the field, positioning him as the leading industry expert — both domestically and globally. His pioneering work led to the development of the MagnaValve, a groundbreaking magnetic media valve, and the acquisition of more than 30 U.S. patents related to shot peening technology. His contributions extended beyond inventions; in 1991, he spearheaded the inaugural Shot Peening and Blast Cleaning Workshop, a milestone event in the industry.

Throughout his career, Champaigne has worked tirelessly to improve processes and formalize standards through professional societies. He has played a key role in leading global shot peening industry associations and groups, earning the moniker "The Shot Peening Maestro," acknowledging his significant impact on the aerospace industry and beyond.

He has been a member of the Society of Automotive Engineers since 1982, receiving the Outstanding Achievement Award Honoring James M. Crawford in 2010, and is Chair of the Aerospace Surface Enhancement Committee. He became a member of the International Scientific Committee for Shot Peening in 1993 and chaired the conferences in 1996 and 2011.

Professor Mario Guagliano

Full Professor of Machine Design, Politecnico di Milano
Chairman of the International scientific Committee for Shot Peening

FROM SHOT PEENING OF HISTORICAL POMPEI WALLS TO THE REDESIGN OF ROMAN WAR MACHINES: A REVERSE ENGINEERING APPROACH

Monil Mihirbhai Thakkar, Politecnico di Milano, Via G. La Masa 1, 20156, Milan, Italy
Amir Ardeshiri Lordejani, Politecnico di Milano, Via G. La Masa 1, 20156, Milan, Italy
Sara Gonizzi Barsanti, Università della Campania Vanvitelli, Aversa (NA), Italy
Mario Guagliano, Politecnico di Milano, Via G. La Masa 1, 20156, Milan, Italy

Biography: Dr. Mario Guagliano is Professor at the Department of Mechanical Engineering, Politecnico Milano, Italy. He has been working for more than 30 years in research related to mechanical surface treatments and processes to improve the mechanical properties of materials and structural components. His present scientific interest is mainly about shot peening application to additive manufactured materials and for surface texturing of metal and polymeric parts. He is also involved in research on cold spray for as a repair, coating and additive manufacturing process. He is and has been coordinator of research projects funded by the European Union, responsible of national projects and of several contractual research, with private and public enterprises and chairman and plenary speaker in several international conferences. He is author or co-author of more than 200 papers international journals, with a H-factor of 53, according to Scopus. Mario Guagliano has been awarded honorary doctor by the University of Zilina (SK) in 2018.

Abstract: The historical site of Pompei is internationally very well known for its unique characteristics. In fact, Pompeii (in Latin Pompeii) is an ancient city, corresponding to the current Pompeii, whose history dates back to the 9th century BC and ends in 79 AD, when, following the eruption of Vesuvius, it was covered under a blanket of ash and lapilli about six meters high. Its rediscovery and the related excavations, begun in 1748 (and still not completed), brought to light an archaeological site with unique features, able to unveil the urbanistic development of Roman cities and some aspects of the everyday life of this Roman town.

However, while the urbanistic organization of the city has been widely studied, there are still aspects related to the Pompei site that have not been investigated and that can help a better understanding of mechanical engineering at the time of the Roman Republic and the early Roman empire.

In this paper, the attention is focused on the indentations due to the impact of projectiles shoot by the war machines used at that time (the "ballista" and the "scorpioni"), whose design concepts and parameters are still not well understood and relay on scripts of the Roman architect and writer Marcus Vitruvius Pollio.

Looking at the wall, in fact, it appears that the wall was shot peened with stone of metal projectiles that left clear indentations (Figure 1).

Starting from the analysis and the digitalization of the experimental indentations, it was possible to develop finite element analysis of the impact of the projectiles against the wall able to correctly eproduce the experimental indentations. The finite element analysis allowed also to determine the shooting parameters in terms of direction, velocity and energy.

Based on these latter data, it was possible to redesign the war machines used at that time for a refined historical reconstruction and a better understanding of the military machines used at that time. This can help better a understanding and interpreting the historical facts that lead Rome to lead to ancient World.

Figure 1 - Pompei wall and indentations caused by the stone and metal projectiles.

Acknowledgement: The research leading to these results has received funding from the MUR - Ministero dell'Università e della Ricerca (Italian Ministry for University and Research) PRIN 2022 program. Project title: Comparative Analysis and Certified Reconstructions for a correct experimental archeology: Roman Scorpions and Ballistae for the Imperial mechanical culture, origin of European identity. Governance policy for the development and sustainable fruition of Cultur-al   Heritage (SCORPiò-NIDI).

Tuesday, September 23rd, 2025

Purdue Memorial Union North Ballroom

8:45 AM	**Welcome to ICSP 15 and Purdue!** Dave Bahr (ICSP15 Chairman)
9:00 AM	**Honoring Professor Kirk** Jack Champaigne
9:15 AM	**Plenary Lecture** From Shot Peening of Historical Pompeii Walls to the Redesign of Roman War Machines: A Reverse Engineering Approach Mario Guagliano

Stewart Hall

10:00 AM	**STEW 214**	
	Coffee Break	
	STEW 202	**STEW 206**
	Industrial Applications 1 (Chaired by: Beach)	Surface Engineering 1 (Chaired by: Balan)
10:45 AM	Shot Peening of Highly Loaded Compression Springs *D. Breuer*	Effect of Shot Hardness on Peening Intensity *K. Balan*
11:05 AM	Fatigue Life Improvement and Residual Stress Retention of Laser Peened AM IN718 and Single Crystal Nickel CMSX-4® Superalloys After Corrosion and Thermal Exposure *J. Fuhr, L. Hackel, K. Davami, M. Munther, N. Morar*	Application of Burnishing Process Expected to Frictional Heat to Non-Oriented Electromagnetic Steel Sheet *Y. Kobayashi, M. Okada, T. Kubo*
11:25 AM	New Electronic Peening Intensity Sensor – Machine Integration for Industry 4.0 *S. Forgues, B. Labelle, R. Ben Moussa*	Enhancing Shot Peening and Blasting Processes With High-Density Ceramic Beads *D. Bouttes, M. Arnold*
11:45 AM	Integration of E-Strip® Technology as a Method of Process Control in Robotic Peening *W. Beach, S. Glaizier, C. Sickler, K. Beach, S. Forgues*	Roughness Parameters for the Evaluation of Blasted or Shot Peened Surfaces *S. Stöckel, S. Gröger*

12:15pm	**PMU South Ballroom**	
	Lunch	
Stewart Hall		
	STEW 202	**STEW 206**
	Industrial Applications 2 (Chaired by: Whalen)	Surface Engineering 2 (Chaired by: Watanabe)
1:25 PM	Methodologies and Applications of the Shot Peen Process to Hole, Slot, or Other Obstructed Geometry *J. Hoffman, J. Whalen, W. Green*	Portable Inspection Technology for Shot Peening as Preventive Maintenance at Steel Bridges *Y. Watanabe, M. Handa, R. Watanabe, K. Hattori, M. Yamawaki*
1:45 PM	The Use of a Dynamic Imaging System to Characterize Particle Size and Shape for Shot Peening Media *R. Sheehan, T. Canty, L. Feltner, P. Mort*	Microstructural Changes and Residual Stress Generation on the Periodically Patterned Surface Texture Fabricated by Angled Fine Particle Peening *Y. Kameyama, H. Sato, R. Shimpo*
2:05 PM	Advancing Shot Peening Quality Control With the Shotmeter: A Modern Approach to Intensity Measurement *D. Lessard, J. Henri, J. Robert, D. Georgaris*	Evaluating the Effectiveness of Localized Masking to Prevent Changes in Residual Stress When Shot Peening *J. Harrison, J. Pineault, S. Carlson*
2:25 PM	Evaluation of Peening Intensity With Nozzle-Mounted Sensor During Processing *A. Matsui, Y. Kobayashi*	Comparison of Anti-Fouling Performance of Textured Glass Surface Fabricated by Ductile-Mode Peening and Precision Grinding *H. Tagaya, Y. Kameyama, S. Kodama, H. Sato, K. Shinagawa, A. Sekiguchi, S. Hirai, H. Ohmori*

Wednesday, September 24th, 2025

Stewart Hall		
	STEW 202	**STEW 206**
	Residual Stress (Chaired by: Schmidt)	Laser & Alternative Peening 1 (Chaired by: Sanders)
8:30 AM	Origin and Interpretation of PSI-Splitting / Out-of-Plane Shear Stress When Using Diffraction Technique *M. Belassel, J. Pineault, M. Brauss*	Cavitation Abrasive Surface Finishing and Peening (CASF) for Cleaning, Smoothing and Fatigue Treatment of Additive Manufactured Components *D. Sanders*
8:50 AM	Residual Stress Relaxation of SMAT-Treated Inconel 718 After Different Thermal Treatments *A. Garambois, P. Kanouté, L. Toualbi, D. Retraint*	Effects of Laser Peening on Fatigue Properties of Welded Aluminum Thin Plates *K. Masaki, Y. Sano, Y. Mizuta, S. Tamaki*
9:10 AM	Dynamic Flowsheet Modeling of Shot Peening Processes *P. Mort, L. Feltner*	Expansion of Laser Peening Application With a High-Power Microchip Laser on a Robotic Arm *Y. Sano, Y. Mizuta, S. Tamaki, T. Hosokai, T. Kato, Y. Sakino, V. Schneidau, S. Holz, J. Behler*
9:30 AM	Enhancing the Fatigue Strength of AM Materials via Mechanical Surface Treatment *J. Schubnell, J. Radners, F. Keil, S. Fliegener*	Creating Heterogeneous Surface Gradient Structure via Ultrasonic Shot Peening *E. Oranli, A. Astaraee, M. Novelli, T. Grosdidier, M. Guagliano, S. Bagherifard*
10:00 AM	**STEW 214** **Coffee Break**	

Stewart Hall		
	STEW 202	**STEW 206**
	Shot Peening of Additive Materials1 (Chaired by: Sealy)	Laser & Alternative Peening 2 (Chaired by: Ferdon)
10:30 AM	The Effect of Fatigue Strength on Shot Peened and Barrel Finished SUS316L Additive Manufactured Products *H. Nishijima, T. Tsuji, Y. Kobayashi, K. Masaki*	Effect of Shot and Laser Peening on the Very High Cycle Fatigue Strength of Additive Manufactured Maraging Steel *K. Takahashi, Y. Kita, G. Nakamura, Y. Furuya*
10:50 AM	Modulating Microstructure, Surface Properties and Fatigue Properties of Additively Manufactured AlSi10Mg Alloy Through Peening Surface Post-Treatments *E. Oranli, A. Amiri, A. Astaraee, M. Bandini, S. Bagherifard, M. Guagliano*	Process Design for Laser Peen Forming of Complex Shape: From Analytical Solution to Peening Pattern *J. Jiang, Y. Hu*
11:10 AM	Hybrid Additive Manufacturing of Polylactic Acid by Fused Filament Fabrication and Shot Peening *E. Parial, M. Sealy*	Effect of Fine Particle Peening Induced Material Transfer on the Inicial Deposition Behavior of Nickel Electroplating on Aluminum Substrate *K. Iijima, Y. Kameyama, H. Sato, S. Kodama*
11:45 AM	**PMU South Ballroom** **Lunch**	

Thursday, September 25th, 2025

Stewart Hall

	STEW 202	STEW 206
	Fatigue 1 (Chaired by: Brown/Padfield)	Industrial Applications 3 (Chaired by: Breuer)
8:30 AM	Numerical Assessment of Shot Peening Contribution to the Fatigue Strength of Gear Tooth Root *G. Cortabitartea, X. Telleria, I. Llavoria, I. Ulacia, M. Larrañaga, J. Esnaola*	Overcoming the Challenges of Robotic Shot Peening With Adaptive Automation *D. Lim*
8:50 AM	The Impact of Surface Finish Treatments on the Fatigue Strength of Shot Peened Al Alloys *M. Bandini, V. Fontanari, C. Menapace, M. Benedetti*	Effects of Spring Shape, Residual Stress and Hardness by Stress Relieving Heat Treatment of Cold-Formed Springs *J. Shin, G. Hwang, T. Sohn*
9:10 AM	Investigations on the Fatigue Strength of Threads Produced by Different Fabrication Techniques *J. Hoffmeister, P. du Maire, A. Öchsner*	Adaptation of Shot Peen Parameters for Gear Geometry *D. Breuer, B. Matlock*
9:30 AM	Reduced Order Approach for Peening Stress Field Variability *L. Feltner, P. Mort*	Dry Laser Peening: A New Laser Peening Technique Without Both Coating and Water Using Femtosecond Laser-Driven Shock Wave *T. Sano*
10:00 AM	**STEW 214** **Coffee Break**	
	STEW 202	**STEW 206**
	Fatigue 2 (Chaired by: Johnson)	Shot Peening of Additive Materials 2 (Chaired by: Adams)
10:45 AM	Influence on Shot Peening and Blast Polishing for Rotating Bending Fatigue Strength of Vacuum Carburized Steel With Circumferential Notch *T. Tsuji, Y. Kobayashi, K. Masaki*	Improvement of the Fatigue Behaviour of Additive Manufactured Scalmalloy by Using Surface Improvement Processes *F. Boby, I. Heras, A. Periñán, J. Sogorb, J. de los Santos, A. Muñoz*
11:05 AM	Effect of Hardness and Residual Stress on Rolling Contact Fatigue Life of Ductile Iron *J. Narasimhan, F. Sadeghi*	Comparison of Peening Effect Between Additive Manufactured and Drawing Titanium Alloy *H. Soyama*

<table>
<tr><th colspan="3">Stewart Hall</th></tr>
<tr><td></td><td>STEW 202</td><td>STEW 206</td></tr>
<tr><td>11:25 AM</td><td>Enhancing High Cycle Fatigue Performance of Electron Beam Melted Ti6Al4V: A Study on Shot Peening and Hot Isostatic Pressing

R. Mamidala, N. Mojib</td><td>Mitigation of Hydrogen Embrittlement in Inconel 718 Produced by LPBF Using Shot Peening

C. Bianchetti, D. Tade, M. Brochu</td></tr>
<tr><td rowspan="2">12:00 PM</td><td colspan="2">PMU South Ballroom</td></tr>
<tr><td colspan="2">Lunch</td></tr>
<tr><th colspan="3">Stewart Hall</th></tr>
<tr><td></td><td>STEW 202</td><td>STEW 206</td></tr>
<tr><td>2:10 PM</td><td>Improvement of Lithium-Metal Electrode All-Solid-State Batteries Performance by Shot Peening and Magnetron Sputtering

A. Okumura</td><td>Novel 3D Optical Metrology for Shot Peen Coverage

E. Novak</td></tr>
<tr><td rowspan="2">2:30 PM</td><td colspan="2">STEW 214</td></tr>
<tr><td colspan="2">Coffee Break</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">STEW 202</td><td>STEW 206</td></tr>
<tr><td>Modeling of Industrial Shot Peening

Chaired by: Feltner</td></tr>
<tr><td>3:15 PM</td><td rowspan="2">ISCSP Meeting</td><td>Reduced Order Approach for Peening Stress Field Variability

L. Feltner, P. Mort</td></tr>
<tr><td>3:35 PM</td><td>Temporal Assessment of Media Mass Flux Uniformity With Multi-Axis Load Cell

L. Feltner, P. Mort</td></tr>
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SHOT PEENING OF HIGHLY LOADED COMPRESSION SPRINGS

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The compression spring in this test study is typical of one used in a demanding off-road vehicle suspension. The cyclic loads applied during fatigue tests were severe enough to cause failure in approximately 11,000 cycles without shot peening.

The objectives of this study were the following: (1) Design a compression spring similar to those used in the off- road recreational industry. (2) Design & manufacture a fatigue test stand that could withstand high loads for months of testing. (3) Generate a matrix of shot peening treatments to produce different amounts of residual compressive stress. (4) Measure the shot peening residual compressive stress via X-Ray Diffraction (XRD). (5) Correlate the residual stress to fatigue life performance. (6) Evaluate the effects of a post shot peening bake cycle on fatigue performance.

FATIGUE LIFE IMPROVEMENT AND RESIDUAL STRESS RETENTION OF LASER PEENED AM IN718 AND SINGLE CRYSTAL NICKEL CMSX-4® SUPERALLOYS AFTER CORROSION AND THERMAL EXPOSURE

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This presentation briefly discusses that all concepts of peening should be considered the same in that the depth of penetration is a direct function of the spot size on the surface by the peening medium. The surface pressure of peening is limited near the yield strength of the metal. This is necessary to prevent surface damage. Consequently, the depth of plastic compression and peening effect is directly related to the spot size on the surface. All spots expand three-dimensionally, so small spots expand spherically and large spots initially expand a plane wave surface and eventually transition to spherical expansion. Ultrasonic cavitation peening creates collapsing bubbles with microscopic water collapse impacts and consequently penetrates to microscopic depths. Shot peening with shot sizes of 0.3 mm to 0.5 mm peen to similar depths, and laser peening with sub-joule energy and resulting surface spot sizes of less than 1 mm peen to 1 mm or less depth. In contrast, Curtiss Wright laser technology has an output energy of 20 J/pulse and uses surface spot sizes of 5 mm to 1 cm. Laser peening spots of this size penetrate to a depth of 5 mm and as much as 10 mm. The depth of peening penetration is particularly important for generating pressures that promote the formation of gamma prime strengthening precipitates in AM IN718 and single crystal CMSX-4.

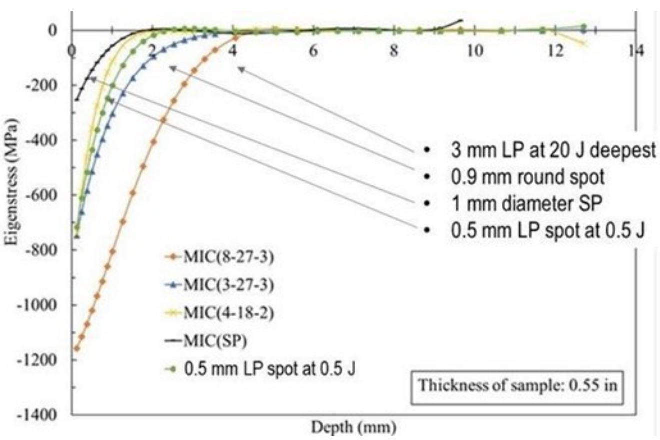

Figure 1. Residual stress shows the depth of penetration of any peening process depends on surface spot size with larger spots generating the deepest compressive stress and smaller spots generating the shallowest stress.

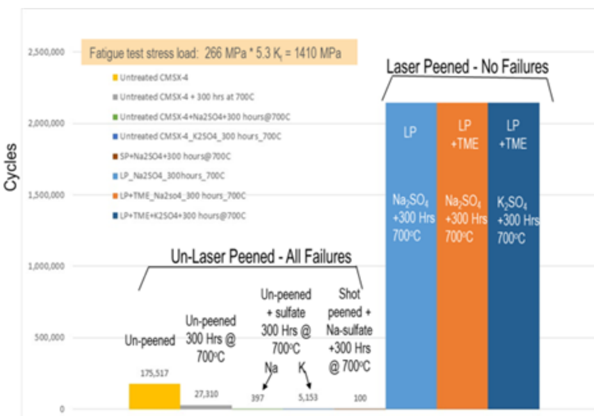

Figure 2. Laser peening of single crystal CMSX-4 shows very short lifetimes vs. long runout fatigue life when specimens are laser peened prior to exposes at 700C for 300 hours and then fatigue tested.

The peening and testing work focused on both AM IN718 provided by Toolcraft GmbH, Germany and a single CMSX-4 provided by Rolls-Royce for the UK Research and Innovation Program. The AM IN718 work showed that the samples treated by laser peening and thermal exposure developed gamma prime precipitates of Ni3Al and Ni3Ti and subsequent significant fatigue life improvement after thermal exposure at 760C and 600C. In this AM material, we believe that laser peening generated dislocations that favored the formation of these precipitates, resulting in resistance to crack propagation at the dislocations.

This AM IN718 shows an 8-times increase in thermal fatigue life after 50 hours exposure at 600C. The single crystal, CMSX-4, was also a Ni-based superalloy with aluminum and titanium elements capable of producing the gamma prime precipitates. In the fatigue tests that followed, painting the specimens with sulfate corrosive and exposing them for 300 hours at 700C, specimens without laser peening gave short lifetimes, while the specimens with laser peening did not fail for the runout duration. In fact, these laser-peened specimens required 2-times the stress load before failure.

NEW ELECTRONIC PEENING INTENSITY SENSOR - MACHINE INTEGRATION FOR INDUSTRY 4.0

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Context

The integration of a wireless shot peening intensity sensor into a computer-controlled shot peening machine represents a significant step forward in achieving precise, automated process control within Industry 4.0 frameworks. This smart sensor measures peening intensity and transmits data wirelessly to the machine's control system, eliminating the need for manual Almen strip manipulation, measurement and recording.

Traditional shot peening relies heavily on operator experience and periodic manual verification to achieve the desired intensity, often leading to inconsistencies and inefficiencies. A dedicated intensity sensor addresses these challenges by offering monitoring and direct feedback of the peening intensity without human intervention. The adoption of such sensors is poised to enhance operational efficiency, reduce costs, and elevate quality standards across the industry, aligning shot peening processes with the demands of modern digital manufacturing.

Objective

This paper will describe the key steps and major components involved in the integration of a wireless shot peening intensity sensor into a computer-controlled shot peening machine. The topics discussed include:

Sensor Deployment: The wireless sensor size and shape to monitor the impact of shot media on the surface being treated, it’s use within the shot peening chamber for machine verification and strategies to maximise operational efficiency for intensity verification in a multi-part, multi-fixture organization.

Data Transmission and Connectivity: The choice of wireless communication protocol and strategies to facilitate data transmission. A typical data workflow will be presented and discussed including the use of Application Programming Interface (API) between the sensor’s computer and the peening machine's centralized control unit.

Process Control and Adjustments: How the peening machine can verify that process parameters stay within specified tolerances to enhance repeatability and quality assurance. How this data can feed into the machine’s control algorithms to allow automatic adjustments of key variables such as nozzle pressure and media flow rate to always ensure optimum peening intensity.

Data Logging and Traceability: All peening data is stored digitally, offering complete traceability for quality audits and compliance with aerospace and automotive standards. The data can also provide predictive maintenance insights based on long-term data trends.

Results

This paper provides strategic insight for process owners to integrate and use wireless shot peening intensity sensors in a computer-controlled shot peening machine. The key steps and major components are discussed and the benefits of such integration are highlighted. By integrating shot peening intensity sensors into smart manufacturing ecosystems, manufacturers will achieve higher efficiency, improved consistency, and reduced downtime, leading to cost savings and enhanced process performance.

INTEGRATINON OF E-Strip® TECHNOLOGY AS A METHOD OF PROCESS CONTROL IN ROBOTIC PEENING

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This paper explores the integration of advanced E-Strip® technology, developed by Shockform Aeronautics Inc., into robotic shot peening processes to enhance process control and consistency. The study adheres to the requirements outlined in AMS2430 Revision U and AMS2430 Revision E as well as the sub-requirements of SAE J442, SAE J443, and SAE J2597. Peening Technologies of Connecticut aims to implement the E-Strip® within their robotic shot peening machines to prove out the concept of data driven process control.

The proposed methodology involves the initial utilization of standard Almen fixtures and test strips to establish computer-generated saturation curves for each test location. Subsequently, the E-Strip® technology is employed to measure baseline intensity values immediately after the creation of saturation curves. Data collection is conducted from both the standard Almen fixture and the E-Strip®.

The primary objective is to accumulate sufficient data to enable the E-Strip® to provide real-time feedback to the machine controller for making necessary process adjustments. These adjustments may include regulating air pressure and shot flow between each part processed or at other predetermined intervals. It is anticipated that this integrated approach will significantly reduce variations in intensity levels observed from part to part and lot to lot.

This paper outlines the proposed methodology, including the integration process of the E-Strip® technology into existing shot peening systems, data collection procedures, and the anticipated benefits of enhanced process control. The findings of this study hold the potential to revolutionize robotic shot peening processes by introducing a novel method for real-time monitoring and adjustment, thereby improving overall process efficiency and product quality.

E-Strip® Description

The E-Strip® has the same size as a J442 Test Strip Holder with the same five M5 screw pattern of 24mm x 40mm. It will therefore fit on most fixtures where it will be easy to remove existing test strip holders and replace them with E-Strip®.

The sensor was designed and built by Shockform exclusively for measuring the impact force of peening media. More than 4 years of Research and Development have gone into the design of the E-Strip®. https://shockform.com/product/e-strip-intensity-measurement-sensor

EFFECT OF SHOT HARDNESS ON PEENING INTENSITY

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Field data has demonstrated shot hardness to be directly proportional to the achieved intensity. This data has been capitalized by shot peeners that were faced with the need to achieve a marginally higher intensity with the drawing notes disallowing increasing shot size.

Increasing the shot size has an adverse effect on part surface coverage, and this can be avoided by selecting a higher hardness of the same size, retaining the number of particles per unit weight.

This test has studied the effect of shot peening with SAE grade media S-110, S-230 and S-550) of three different range of hardness (S, M and H). The testing also included AMS grade cast steel shot, ASR-170 and ASH170 at 40 PSI and 70 PSI). The velocity when peening with compressed air at 70 PSI closely simulates that generated by a blast wheel at around 240 FPS.

The hypothesis that the increase in arc height is exponential at larger shot sizes will be tested by this study. The results from this test will help users understand the intensity limitations placed by shot of a particular hardness. It will help users re-design their process when the demand is for a higher intensity and constraints placed on use of a certain shot size.

Note: An article was published in The Shot Peener magazine, Winter 2025 that provides data and analysis of the test results. Shot Size	Hardness	Air Pressure
S-70	S	40
S-70	S	70
S-70	M	40
S-70	M	70
S-70	H	40
S-70	H	70
S-110	S	40
S-110	S	70
S-110	M	40
S-110	M	70
S-110	H	40
S-110	H	70
S-230	S	40
S-230	S	70
S-230	M	40
S-230	M	70
S-230	H	40
S-230	H	70
S-550	S	40
S-550	S	70
S-550	M	40
S-550	M	70
S-550	H	40
S-550	H	70

APPLICATION OF BURNISHING PROCESS EXPECTED TO FRICTIONAL HEAT TO NON-ORIENTED ELECTROMAGNETIC STEEL SHEET

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Electromagnetic steel sheet is a material used in motor cores and transformers. As a crystal property of electromagnetic steel, grain refinement is observed on near the surface. This is due to the rolling process. On the other hand, various losses when power is converted into magnetic force decrease with larger crystal grains. Therefore, larger crystals grains are required. In the previous study, it was reported that shot peening can improve electromagnetic properties by improving the orientation of the electromagnetic steel.

Burnishing is a machining method in which a rotating tool is moved while pressing against the surface of the workpiece. Generally, the expected effect of burnishing is to reduce surface roughness. Normal burnishing tools are made of materials such as tool steel or cemented carbide. Various coatings may also be applied to prevent adhesion. When burnishing is used to improve the properties of electromagnetic steel, the surface crystal properties are expected to change. When trying to change the crystal properties of a metal, it is better to be at a high temperature.

The thermal conductivity of zirconia is 1/20 that of iron. When ferrous materials are processed by burnishing, most of the heat generated by the process is transferred to the work piece.

In this study, zirconia balls were used as burnishing tools, and changes in crystal properties were confirmed when electromagnetic steel were processed. Thereafter, changes in crystal properties were confirmed by EBSD and other methods. The amount of power generated by the burnished electromagnetic steel plates was also investigated.

As a result, power generation by the burnished specimens was worse than that of the unburnished specimens. However, there were differences in the burnishing conditions and in each frequency.

Eddy current losses at high frequencies are proportional to the square of the frequency. The decreasing in power generation was reduced in the electromagnetic steel sheet processed using zirconia, especially in the high frequency range. Therefore, eddy current losses at high frequencies might be reduced. On the other hand, the decreasing in power generation was due to the total deformation of the electromagnetic steel sheet caused by the processing.

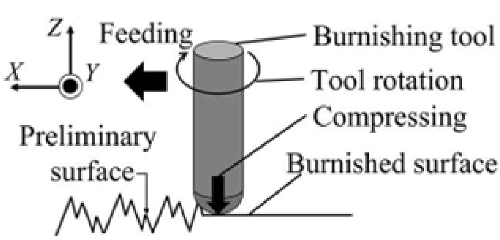

Fig.1 Method of burnishing

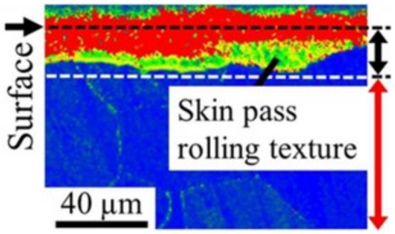

Fig. 2 KAM Map of non processed specimen.

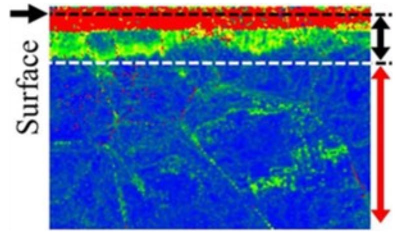

Fig. 3 KAM Map of specimen after burnishing

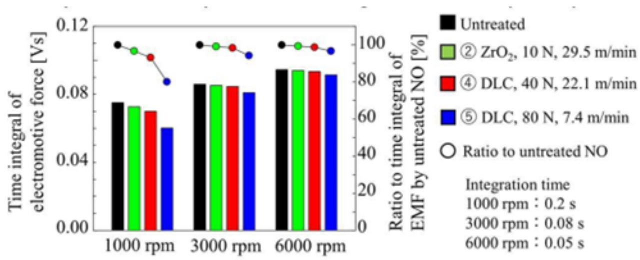

Fig.4 Comparison of power generation by burnishing conditions

ENHANCING SHOT PEENING AND BLASTING PROCESSES WITH HIGH-DENSITY CERAMIC BEADS

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Magali Arnold, Saint-Gobain Research Provence

Shot peening and blasting processes are widely utilized in various industries for applications such as part cleaning, surface roughness control, residual stress induction to enhance fatigue life, and microstructural refinement for improved corrosion resistance. As these processes continue to evolve, they face new challenges and emerging applications. Growing concerns over cost and environmental impact drive the demand for more energy-efficient techniques that minimize waste and reduce the need for decontamination. Additionally, the advent of additive manufacturing introduces specific requirements for precise surface roughness control, while the hydrogen economy presents novel corrosion management challenges.

In this study, we present several case studies addressing these challenges through the use of high-density ceramic beads composed of stabilized zirconia. These beads, characterized by their higher density and toughness compared to traditional silica-zirconia media, offer significant advantages in blasting and peening applications. We begin by evaluating the media lifespan in comparison to standard media types—metallic shots, ceramic shots, and glass beads—since this metric is crucial for overall cost analysis. Subsequently, we explore various application scenarios to assess the performance of these ceramic beads, focusing on: surface roughness control for components produced via additive manufacturing, microstructural refinement beneath the surface to enhance corrosion resistance, and shot peening of high-strength steel and other alloys to induce intense residual stresses.

Our results demonstrate that the ceramic beads exhibit an exceptional lifespan relative to their non-metallic counterparts, and their longevity also compares favorably to metallic shots when projection velocities are maintained below 50 m/s. Due to their high hardness, these beads are particularly effective in creating surface roughness and inducing residual stresses. When coupled with optimized process parameters, they can achieve innovative finishes and generate substantial residual stresses, thereby contributing to enhanced performance in various applications.

ROUGHNESS PARAMETERS FOR THE EVALUATION OF BLASTED OR SHOT PEENED SURFACES

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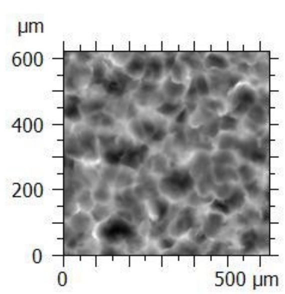
Surface texture represents a connecting link between the manufacturing process and the function of the workpiece. In ISO 21920-2, it is defined as the geometrical irregularities contained in a filtered profile, excluding the underlying form [1]. By applying a filter, the roughness, defined as the small lateral wavelength, can be derived and described by means of the calculation of roughness parameters (R-parameters). Furthermore, the determination of areal surface texture in accordance with ISO 25178-2 and the calculation of areal parameters (S-parameters) are also possible [2].

A review of the papers presented at the 2022 ICSP conference revealed that the most used parameters are Ra and Rz. It is notable that there has been comparatively little exploration of other parameters, particularly the S- parameters. Furthermore, the ISO 4287 standard for profile parameters was replaced by the new ISO 21920-2 standard in 2021 [2,3]. This is accompanied by the introduction of new parameters.

This paper demonstrates the limitations of Ra and Rz, as well as Sa and Sz, and explores additional areal and profile parameters that are useful for the description of blasted or shot peened surfaces. Additionally, the advantages and disadvantages of profile and areal measurements are illustrated. Surfaces that have been blasted for varying periods of time serve as illustrative examples. Two of them are presented in Figure 1. The areal measurements provide a clear indication of the structural differences. Following a two-minute exposure to a wheel blast machine, residual initial surface material is still visible, and the resulting impacts are smaller in comparison to the surface after 20 minutes of blasting. Both surfaces result in the same value for Sa and similar Sz, whereas Sdr and especially Sal show bigger differences. These parameters, as well as others, are further investigated.

2 min



Sa	1,96 µm
Sz	17,90 µm
Sdr	3,72 %
Sdq	0,292
Sal	29,6 µm

20 min

Sa	1,95 µm
Sz	15,90 µm
Sdr	1,86 %
Sdq	0,199
Sal	42,2 µm

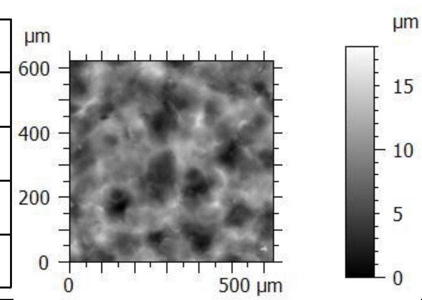


Figure 1 Comparison of selected areal roughness parameters for blasted surfaces with varying production time

In conclusion, it is recommended that, in addition to Ra and Rz, further parameters should be considered for the analysis of blasted surfaces in experimental design or process control. The use of areal measurements can facilitate a more comprehensive understanding of the overall surface, given that blasting does not result in a regular structure with a strong directional component as in turning. The paper presents parameters that have been identified as potentially useful, along with an explanation of their significance.

References

[1] ISO 21920-2:2021 Geometrical product specifications (GPS) — Surface texture: Profile - Part 2: Terms, definitions and surface texture parameters

[2] ISO 25178-2:2021 Geometrical product specifications (GPS) — Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters

[3] ISO 4287:1997 Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters

Abstracts

Industrial Applications 2

METHODOLOGIES AND APPLICATIONS OF THE SHOT PEEN PROCESS TO HOLE, SLOT, OR OTHER OBSTRUCTED GEOMETRY

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Will Green, Progressive Surface

Applying an accurate shot peen process to hole, slot or other obstructed geometry can present some challenges for a process engineer. Often, a few different methods available that could be used to apply the peening process to such geometry. This technical paper will focus on the most common acceptable methods, the pros and cons of each method as well as intensity and stress measurement data. We will apply each of these methods to evaluate coupons made from different metal alloys. The alloys chosen are some of the more common metals that often benefit from shot peening for increasing component life and durability. Each coupon will then be analyzed for the residual stress values. In addition to the stress measurements, surface roughness data will be collected as well to determine if the selected method has any adverse effects on the resultant surface topology.

The methods outlined in this paper will be limited to quadrant peening with a standard straight bore nozzle and a deflector style lance using full Almen strips. We will also discuss the use of partially shaded Almen strips and mini Almen strips to determine Intensity. Understanding each method, as well as the effects of each method, will help the process engineer chose the best approach to their shot peening application.

An intensity range will be selected for each alloy, representing typical ranges used throughout the industry. This testing will only cover the use of steel shot as a peening media as this is the most common type used in peening applications. All the test coupons will have each shot peen method applied to it. This will allow a direct comparison between the selected methods and highlight any potential negative or positive effects each may have. Each method will use Almen strips to gather the intensity data and X-ray diffraction will be used to measure the residual stress values of each test coupon. Surface roughness data will be collected using a profilometer.

The goal of this research project will be to understand these peening applications more thoroughly, highlights the differences in applying the process and to define the proper implementation of each method.

THE USE OF A DYNAMIC IMAGING SYSTEM TO CHARACTERIZE PARTICLE SIZE AND SHAPE FOR SHOT PEENING MEDIA

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Shot peening is a cold working process that enhances the mechanical properties of components such as springs, axles, and gears. Shot media are projected at a high velocity against the material's surface, creating a layer of compressive residual stress that improves fatigue and wear resistance of the material. The size and shape of the media affect the residual stress layer that is created. To ensure consistent quality, it is critical to characterize and control the particle size and shape distribution of the shot media, both as-manufactured and in the working mix. This paper presents how the use of a dynamic imaging system developed by J.M. Canty can provide the size and shape measurements that are necessary for an efficient shot peening process.

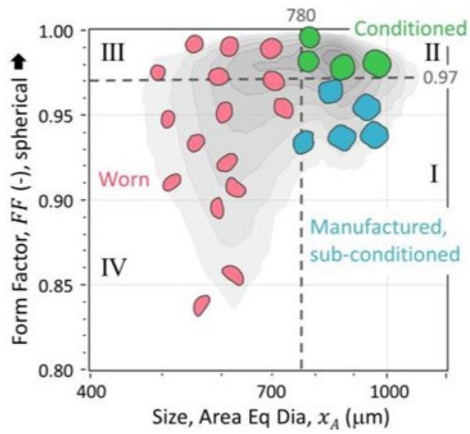

Fig 1. Size/shape quadrant map, CW32 media, showing volume density (grayscale contours) overlaid by outlined images.

J.M Canty's SolidSizer is a dynamic imaging system that measures multiple size and shape parameters of dry material such as shot media. The system has particles fall off a vibratory feeder between a microscopic camera and LED light, continuously capturing images of the particles in free fall. This system includes software that performs analysis on each of the images taken throughout the duration of the sample. Over 40 different size and shape parameters can be measured, recorded, and graphically displayed; many features are based on 2D projections of area, 퐴, and perimeter, 푃. Current J- specs prescribe sieve characterization of shot media, which only gives 1D size data and not the 2D shape data that is critical for understanding how shot media affects the shot peening process. For example, sieve data tend to correlate with the minimum Feret diameter, 푥퐹푒푟푚푖푛, while the 2D area-equivalent diameter, 푥퐴 = √4퐴⁄휋, better represents the shot mass impacting the work piece.

The typical lifecycle of in-use steel shot progresses through stages shown in Figure 1: I) as-manufactured; II) conditioned, and III-IV) worn [1]. Media suffering from excessive wear are removed by a screen-classifier. The media recycle loop is replenished with as- manufactured media in proportion to the mass removed. Media shape can also change with use. Typically, there is an initial improvement in roundness, shown as Form Factor, 퐹퐹 = 4 휋퐴⁄푃2, increases from I to II in Fig. 1. Wear can result in marginally smaller media with rounded shapes (III) or more severe breakage (IV).

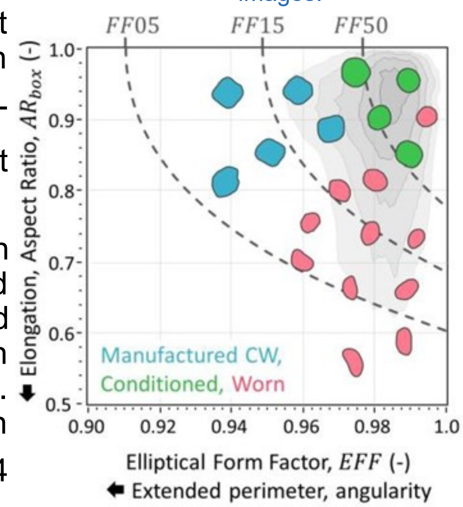

Fig 1~~2~~. Detailed shape map, CW32 working mix, showing volume density (grayscale contours) overlaid by outlined images and 퐹퐹 percentiles (dashed lines).

Detailed shape characterization compares the effect of perimeter irregularity with elongation (Fig. 2). Elongation is the aspect ratio of minor/major axes, 펌퓑 = 퓨퐹퓔퓢퓔/퓨퐹퐹; elliptical form factor, 퐰퐹퐹 =

훽훯펌/퐶2, 훽 = (1.5 · (펌퓑 + 1)√펌퓑 − 1)2, is the ratio of an ideal elliptical

surface having the measured AR to the perimeter-extrapolated surface. The two measures are orthogonal and illustrate the proximity to a spherical shape (1,1). Combined evaluation of size and shape provides an in depth understanding of what leads to an effective shot peening process.

[1] L. Feltner, M. Gruninger, T. Canty and P. Mort, "Characterization of Particle Size and Shape Distributions for Shot Peening Media," The Shot Peener, Spring 2033.

ADVANCING SHOT PEENING QUALITY CONTROL WITH THE SHOTMETER: A MODERN APPROACH TO INTENSITY MEASUREMENT

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Shot peening is a critical surface treatment process that enhances material properties by inducing compressive residual stress, improving fatigue life, and resistance to stress corrosion. Traditionally, the intensity of the process has been measured using Almen strips, which rely on saturation curves to determine arc heights after peening. While effective, this trial-and-error method is time-intensive, requiring multiple iterations to optimize process parameters. The Shotmeter, a product by Tecnar Automation in collaboration with Progressive Surface, offers a reliable and versatile solution for measuring and controlling shot peening intensity, addressing longstanding challenges in process efficiency and consistency across diverse applications, including aerospace, medical, and automotive industries.

The Shotmeter–G3 system employs a dual fiber-optic device that detects particle flow at two precisely spaced measuring points along the spray stream. Brightness signals detected by a sensor are analyzed through cross- correlation to calculate the time delay between the two points. Since the gap is constant and precisely known, velocity is determined with accuracy within 2%.

This innovative approach complements the use of Almen strips for process control. Velocity measurements can be integrated with multiple systems, enabling seamless process monitoring, parameter adjustment, and data archiving. The Shotmeter provides actionable insights into particle velocity, media flow rates, and their direct correlation to intensity. Through empirical models and machine-specific velocity fingerprints, operators can predict intensity profiles without relying on time-consuming saturation curve development.

In addition to accelerating development, the Shotmeter serves as a robust troubleshooting tool. It facilitates periodic machine health checks by detecting anomalies in velocity profiles, enabling operators to diagnose issues such as nozzle wear or media inconsistencies. In one instance, an aerospace manufacturer resolved production disruptions by identifying faulty Almen strips, leveraging Shotmeter data to isolate the root cause within days rather than weeks.

The Shotmeter supports consistent process quality by providing velocity measurements at specified intervals to ensure compliance with established process limits and prevents defective parts from advancing through production. The system's capability to halt operations and trigger maintenance or quality alerts in case of deviations highlights its role as a critical safeguard in modern manufacturing environments, enabling quality-driven manufacturing practices.

The Shotmeter represents a groundbreaking tool that redefines shot peening by offering precise intensity measurement, rapid process optimization, and reliable performance monitoring. It represents a significant step forward in achieving greater efficiency, accuracy, and quality in surface treatment processes. This advancement not only addresses longstanding challenges but also sets a new standard for the shot peening industry.

EVALUATION OF PEENING INTENSITY WITH NOZZLE-MOUNTED SENSOR DURING PROCESSING

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Yuji Kobayashi, SINTOKOGIO, LTD.

Introduction

In recent years, the using of digital technology in the manufacturing industry has become increasingly active. In production equipment, visualization of equipment status and anomaly detection have been reported. Similar activities have been reported in the field of shot peening.

Arc height and peening intensity are used as process management indicators for the shot peening process. The processing parameters of the shot peening machines are set to satisfy the specified peening intensity or arc height. The arc height is represented by the amount of curvature when shot peening is processed on one side of an Almen strip.

The measurement of arc height contains many steps, degreasing, mounting on a Almen holder, shot peening, removing the Almen strip, and measuring the amount of curvature. In order to decide peening intensity, it is necessary to draw a saturation curve. Since the saturation curve requires more than four arc height values, arc height measurements are repeated until the saturation curve can be drawn.

If the optimal conditions are not achieved, it is necessary to adjust the processing parameters of the shot peening machine and re-measure the arc height and decide the peening intensity. Evaluation of peening intensity requires much working time. Therefore, it is considered that if there is sensing technology that can output peening intensity, the demands on workers can be decreased.

Objectives

In this report, the peening intensity is evaluated by the sensing technology. The relationship between peening intensity and output obtained by the sensing is researched.

Methodology

An air-type shot peening machine is used for the experiment. This machine uses a nozzle to eject the shot media and compressed air. A sensor is attached on the nozzle to measure the AE wave. It is acquired by AE sensor. The shot media is used conditioned cut wire (CCW). The peening intensity is determined by the software for intensity calculation. The specific parameter is calculated using the sensor output values. It is used for comparison with the peening intensity.

Results

As a result, the correlation with the specific parameter and the peening intensity, a correlation is confirmed. From this result, it is considered that the peening intensity can be evaluated using sensing.

PORTABLE INSPECTION TECHNOLOGY FOR SHOT PEENING AS PREVENTIVE MAINTENANCE AT STEEL BRIDGES

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Shot peening has been used for many applications in Japan. Preventive maintenance for steel bridge infrastructure is one of the applications. Inspection methods after shot-peening the steel bridge are 1) a coverage measurement by UV light and 2) a residual stress measurement by a portable X-ray diffraction device that allows performing on-site measurement. However, the general residual stress measurement only evaluates the stress value just at the surface. We have previously reported on a positron lifetime measurement method that can evaluate atomic-level defects, i.e., dislocations, near the surface. At this time, we examined whether our newly developed portable positron lifetime measurement device can capture the peening effect at deeper than the surface level.

First, shot peening was performed on steel materials for a steel bridge at several different coverage, and the coverage values and surface residual stress were measured. We used UV Coverage Checker to evaluate the coverage value. Then, the positron lifetime was measured by using a newly developed portable positron lifetime measurement device, and the relationship between the coverage values and residual stress values was evaluated. The positron lifetime increased as the shot peening coverage increased. However, the residual stress value at the surface tended to decrease the compression value, which was an opposite phenomenon. In general, as the peening treatment time increases, we expect that the residual stress deepens toward the inside, and the surface tends to shift to the tensile side. However, the strength of bridges increases with the shot peening time; thus, only measuring the residual stress value at the surface does not reflect the peening effect on the bridges. Therefore, the characteristics of positrons, which capture the peening effect near the surface, can show much more real phenomenon. In conclusion, we determined that more accurate peening evaluations are possible by using the portable positron lifetime measurement device in this case.

We also investigated the evaluation of the rust on steel bridges. When weather-resistant bridges are used for many years, especially around the coast, it is more likely to deteriorate the weather-resistant bridges quickly, which requires additional painting for maintenance. However, whether the bridges get rust and need maintenance is determined visually in Japan now, and the visual inspection is considered subjective. Therefore, an alternative reliable method is desired for the situation.

We used the newly developed portable positron lifetime measurement device to see if the device can measure the situation of rust on bridges. The test results showed that the positron lifetime increases as the rust progresses on the bridge. The device also provides numerical data with which we can determine whether additional painting is necessary or not.

We believe that these evaluation technologies will be effective for infrastructure maintenance in the future.

MICROSTRUCTURAL CHANGES AND RESIDUAL STRESS GENERATION ON THE PERIODICALLY PATTERNED SURFACE TEXTURE FABRICATED BY ANGLED FINE PARTICLE PEENING

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Surface texturing technology has been emerging because of its potential to provide various surface functions such as friction reduction, wettability control, improvement of biocompatibility, and so on. In addition to the conventional and important roles of improving the strength of machine components, shot peening has been attracting engineers as a texturing technology. Although the surface textures created by shot peening can vary depending on the choice of the shot particle diameter and shape, and peening conditions, they typically comprise peaks and dimples aligned isotropically but randomly. The authors have proposed a specific peening technique to fabricate periodic ridge texture with several tens or hundreds of micrometers in size, namely angled fine particle peening, hereinafter angled-FPP. Angled-FPP is a unique peening process that can fabricate patterned surface structures without masking. Previous studies on the angled-FPP have been focused on the surface functions achieved by the periodic surface structures and demonstrated that those with an appropriate size were beneficial to reduce friction, promote cell patterning, and so on.

In angled-FPP, shot particles with a diameter of 200m m or less bombard the surface to be peened at an inclined angle. When metallic materials were subjected to angled-FPP, the colliding particles slid at the material surface, forming bumps of the dragged material (Fig.1). These are likely precursors of the ridge structure. This scenario implies that severe and specific plastic deformation drives the texture formation, and therefore suggests great impacts on the microstructure evolution and residual stress generation by angled-FPP. This study aimed to investigate the effects of angled-FPP on microstructure and residual stress of peened material.

The angled-FPP experiment was performed on aluminum alloy using steel shot particles with varying peening times. Periodically aligned peaks and valleys transversely to the particle flow direction were formed and grown with increasing peening time (Fig.2). As material transfer from steel particles to the aluminum substrate occurred during the peening process, followed by mechanical mixing of the transferred fragments into the substrate, a lamellar microstructure consisting of iron and aluminum was developed along the ridge surface. Residual stress measurement revealed that compressive residual stress was successfully generated by angled-FPP. A higher absolute value of the compressive residual stress was determined along the ridge alignment. This implied that the compressive residual stress field by angled-FPP was anisotropic. The specific features of angled-FPP surface were exhibited.

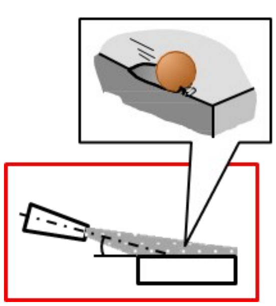

Fig.1 Schematic illustration of angled-FPP

(a) Peening time: 2s (b) Peening time: 8s (c) Peening time; 30s

Fig.2 Development of the periodic ridge structure with peening times of angled-FPP.

EVALUATING THE EFFECTIVENESS OF LOCALIZED MASKING TO PREVENT CHANGES IN RESIDUAL STRESS WHEN SHOT PEENING

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When shot peening components, it is common practice to mask certain localized regions where peening roughness is not desirable. For example, surfaces that have been highly machined such as bearing races or areas of interference-fit may require masking to protect them from plastic deformation due to shot peening. Oftentimes shot peening the grip sections of fatigue test coupons can prevent cracking and failures due to fretting fatigue in the grip area but could affect the outcome of the test if applied to the gauge section of the coupons. Thus, maintaining an “as machined” surface roughness is the most common reason for masking an area when shot peening, where no-observable-dimples is the quality standard. In the aerospace industry, masking is also used on thin areas to prevent distortion or changes to the shape of the part. There are several techniques commonly used for masking. For high production parts, permanent masking tools are often made from rubber or abrasion resistant ultra-high molecular weight (UHMW) plastics whereas tape is commonly used when a lower quantity of parts is being shot peened. However, the Authors of this paper could not find any specifications in the literature that describe either what a suitable thickness of the tape should be, or how many layers of tape should be used for any given peening intensity and coverage. As common practice today, one “layer” of tape is typically used for lower peening intensities whereas two “layers” are normally used when peening at higher intensities.

The question that this research aims to answer is, even though dimples from peening may not be apparent, was there some level of compressive stress introduced in taped regions that could change the performance characteristics in presumably “tape-masked” regions? To answer this question, a comprehensive test plan was developed to map residual stresses using X-ray Diffraction (XRD) in a series of 7050-T7451 aluminum alloy coupons that were masked with various tape thickness’ and shot peened using various peening intensities. Regions that were shot peened with and without tape -masking were characterized, as well as transition regions since some modeling efforts predict that tensile residual stresses directly at the transition area could create a stress concentration.

The following paper discusses the results obtained and conclusions derived from this research.

Keywords

Shot Peening, Tape, Masking, Residual Stress

COMPARISON OF ANTI-FOULING PERFORMANCE OF TEXTURED GLASS SURFACE FABRICATED BY DUCTILE-MODE PEENING AND PRECISION GRINDING

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Recently, there has been a growing demand for precision processing of glasses. Not only shape accuracy, surface texturing of glasses, which fabricates microscale geometries on the surface, is emerging to promote various surface functions. For example, the cover glasses of solar cells require anti-fouling performance to prevent dirt adhesion because dirt deposition on their surfaces decreases transparency, reducing electricity generation. There is a concern that water spots might form when rain does not completely wash out the dirt deposited on the glass surface. It is known that the van der Waals force, which promotes adhesion between dirt and an object surface, depends on the surface roughness of the base material to which the powder adheres, and decreases as the true contact area between the powder and the base material reduces. Therefore, precise surface processing technologies possibly affect powder adhesion behavior onto the processed surfaces because they can vary the surface structure and topography. The authors have proposed a specific fine particle peening technique that can fabricate precise surface texture on glass surfaces. This study aims to evaluate the anti-fouling performances against powders derived from surface structures fabricated by various surface processing techniques, including the proposed peening technique.

Angled-FPP, in which fine particle peening is performed to glass from an oblique angle, formed specific collision dents where the glass was plastically deformed. This was because an individual particle slides on the surface and simultaneously penetrates there when colliding with the surface. Such a peening inducing ductile manner processing mechanism, namely “ductile-mode peening of glasses” successfully created microscopic surface texture while maintaining transparency.

ELID grinding, a precision grinding process that performed in-process electrolytic dressing to maintain the sharpness of the grinding wheels, was also employed to fabricate surface structures and compared with the peened surface. ELID grinding under appropriate conditions reduced damage to the workpiece compared to conventional grinding and controlled the depth of cut by individual abrasive grains during the grinding process, achieving a mirror-finished surface via ductile-mode grinding. The dimple array structures and planarly ground surfaces were fabricated by ELID grinding.

The processed glass specimens were then examined by a specially developed powder adhesion test, where a silicon powder with an approximate diameter of 110 μm was sprinkled on the specimens, followed by tilting the specimens. The powder should detach from the surface by gravity when the specimens were tilted, and then the area ratio occupied with the remaining powder was measured via image processing to evaluate anti-fouling performance; the lower the area ratio the lower the area ratio, the better anti-fouling performance. Results indicated that all glass samples prepared with angled-FPP, ELID grinding with varied conditions, and plain surface without any processing exhibited a low area ratio of remaining powder, indicating good anti-fouling performance.

The difference in powder adhesion behavior between the peened specimen and the plain one was not very clear in this study. The area ratio of adhesion exceeded 15% more frequently in glass processed by ELID grinding and less frequently in glass processed by Angled-FPP.

ORIGIN AND INTERPRETATION OF PSI-SPLITTING / OUT OF PLANE SHEAR STRESS WHEN USING DIFFRACTION TECHNIQUE

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Psi-splitting is a phenomenon often observed in interplanar d-spacing vs. $\sin^2\psi$ plots during the analysis of residual stress measurement data when employing the X-ray diffraction (XRD) method. Deviations from the expected linear relationship between interplanar d-spacing and $\sin^2\psi$ are typically caused by the presence of out-of-plane shear stresses or inhomogeneous stress distributions within the measured phase of the material. In such cases, the d-spacing values measured at different ψ tilt angles deviate from the anticipated linear trend, resulting in a characteristic splitting of the d-spacing vs. $\sin^2\psi$ plot data. In such cases, the shape of the data in the plot will take the form of an ellipse. When this occurs, the stress state in the material cannot be accurately described by a simple biaxial stress model, necessitating a more comprehensive analysis to account for the triaxial nature of the stress field and to accurately calculate the components of the stress tensor. Most critically, the presence of non-zero out-of-plane shear stresses directly affects the accuracy of the normal stress tensor components being determined. Psi-splitting typically occurs in inhomogeneous and multiphase materials subjected to cold working processes such as machining, shot peening, or other surface treatments.

This paper aims to explain the origin and mechanism of Psi-splitting, detailing how it occurs and how it should be interpreted in single and multiphase materials. It also seeks to bridge the gap between materials scientists and mechanical engineers. It is important to note that this phenomenon does not alter the biaxial macroscopic stress state of the material, and that the boundary conditions at the surface remain valid because the overall effect is balanced at the macroscopic level when considering all constituent phases present in the material.

RESIDUAL STRESS RELAXATION OF SMAT-TREATED INCONEL 718 AFTER DIFFERENT THERMAL TREATMENTS

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Mechanical surface treatments are widely used in the aerospace industry with the dual objective of improving the surface properties of critical components and delaying fatigue crack initiation. Indeed, fatigue damage has been identified as the primary failure mechanism for turbine disks, with crack initiation occurring predominantly on the surface. Surface Mechanical Attrition Treatment (SMAT) is a process derived from ultrasonic shot peening that creates a nanocrystalline layer at the surface of treated mechanical parts in addition to superficial compressive residual stress and strain hardening. Previous studies have shown that SMAT can enhance yield strength [1], ultimate tensile strength, and fatigue life [2] of metal parts, but limited research has focused on Ni-based superalloys, particularly with regard to their fatigue behavior at elevated temperatures. Given the thermal and mechanical loads experienced by aerospace components, understanding the relaxation of SMAT-induced residual stresses and the associated changes in material properties is essential to accurately assess its impact on component durability and reliability.

This study aims to characterize the property gradient induced by SMAT and its evolution under thermomechanical stress. Experiments were performed on Inconel 718, with two different sets of SMAT parameters. Residual stress profiles after different thermal treatments were evaluated using X-ray diffraction (XRD) combined with layer removal by electrolytic polishing for depth-resolved measurements. Work hardening changes induced by SMAT were estimated from three variables: microhardness, local crystal misorientation measured by EBSD, and full width at half maximum (FWHM) of XRD diffraction peaks.

Existing literature and experimental data indicate that SMAT-induced microstructural modifications are confined to the first few hundred micrometers of the surface and can significantly influence the mechanical response of the material under thermomechanical loading. To further investigate these effects, in situ SEM four-point bending tests were performed at 20°C and 450°C on both untreated and SMAT-treated samples. Digital Image Correlation (DIC) was used to capture local strain fields at an appropriate scale, to provide insight into deformation mechanisms. In addition, fatigue tests were performed at the same temperatures to evaluate the effect of SMAT on the cyclic behavior and lifetime of the material.

Ultimately, these characterizations will serve as the basis for a fatigue life model that incorporates the SMAT- induced property gradient, contributing to a more reliable assessment of aerospace component durability.

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DYNAMIC FLOWSHEET MODELING OF SHOT PEENING PROCEESES

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Process flowsheet modeling is used to map and predict performance by integrating sub-models within a system. This paper presents a dynamic flowsheet for shot peening used to track the effects of media characteristics, removal of worn media, and replenishment thereof. Input parameters include media characteristics, media feed rate, velocity (i.e., air pressure), effective impact area (i.e., nozzle setup), and recharge replenishment; Figure 1a illustrates a shot peening flowsheet with characteristics for CW32 media. Media size and shape characteristics were obtained using dynamic image analysis (Solidsizer, JM Canty, Lockport, NY) treated over multiple impact cycles (Ervin Test Machine, Ervin Industries, Adrian, MI) along with working mix samples obtained from in-plant trials.1

The media working mix is described dynamically using tri-modal size and shape characteristics: as-manufactured, conditioned, and worn modes (Figure 1b), each having impact-dependent rate coefficients for transition to the next mode, i.e., as-manufactured $\rightarrow$ conditioned $\rightarrow$ worn $\rightarrow$ debris. In the current version of the flowsheet, the effect of classification efficiency is lumped into the worn $\rightarrow$ debris rate expression.

The flowsheet includes the effect of media shape by linking the curvature at peening impacts with a reduced- order FEM model (Fig. 1c-d). A machine-learning execution of the reduced-order model enables residual stress predictions directly from coverage simulations within a representative volume element (RVE). As a further model reduction, the flowsheet tracks statistical representations of residual stress and variability thereof.[2]

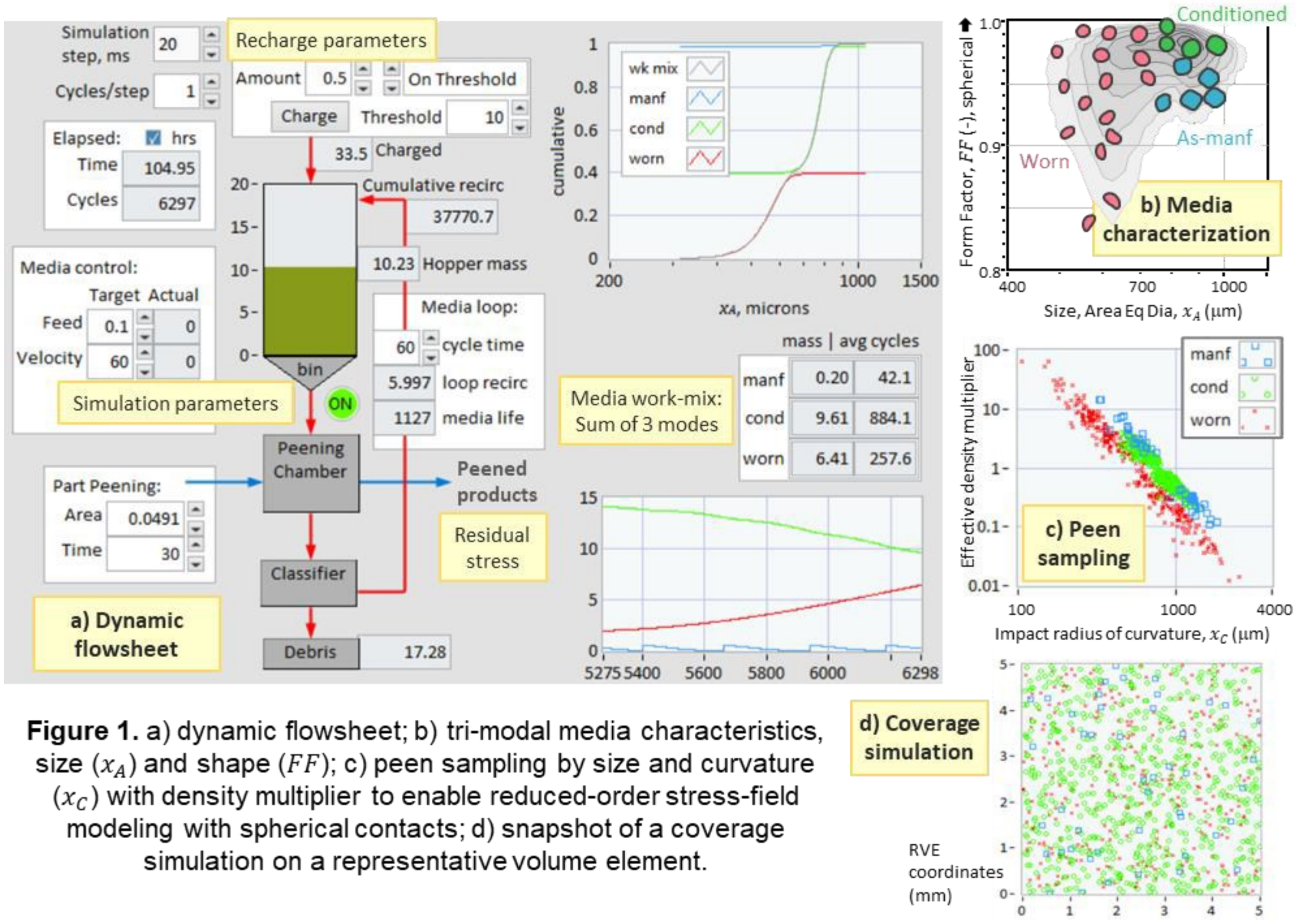

Figure 1. a) dynamic flowsheet; b) tri-modal media characteristics, size (x_A) and shape (FF); c) peen sampling by size and curvature (x_C) with density multiplier to enable reduced-order stress-field modeling with spherical contacts; d) snapshot of a coverage simulation on a representative volume element.

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ENHANCING THE FATIGUE STRENGTH OF AM MATERIALS VIA MECHANICAL SURFACE TREATMENT

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Additive manufacturing (AM) processes, such as powder-based or sintering methods, offer a high degree of flexibility to produce parts with complex geometries, even for structural applications that typically require a high strength of the components. However, the poor surface quality of as-built parts results in a low fatigue strength compared to conventionally manufactured components. Thus, the use cases for metallic AM components in safety relevant applications such as aviation and transport are currently limited. Reasons for the poor fatigue strength are the harmful tensile residual stresses, high surface roughness and defects such as pores or lack-of-fusion (LOF) near the surface layer, see Figure 1 (left). These notch-like features act as crack initiators. To improve the fatigue strength of the surface layer, mechanical surface treatment (MST) methods offer great potential, e.g. shot peening or deep rolling, illustrated in Fig. 1 (right) are widely used for post-treatment of conventionally manufactured components. However, relatively few studies exist for AM materials. In the ongoing project at Fraunhofer IWM MST methods such as conventional shot peening and deep rolling are investigated to improve the properties of additively manufactured AlSi10Mg and 316L parts. In addition to experimental investigations to characterize the surface layer and the fatigue strength of different material states, the MST process is modelled via finite-element-based process simulation, see Fig. 2 (left). A strain-rate dependent cyclic plasticity model with kinematic hardening is applied to account for the material behavior during the shot peening and deep rolling processes, see Fig. 2 (right). As a perspective within the project, the developed methodology will also be applied to demonstrator components, considering the MST in a dimensioning scheme similar to the German FKM guidelines widely used in the industry.

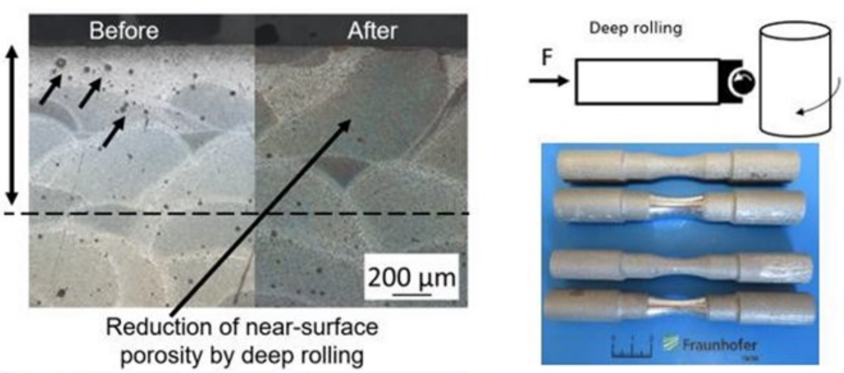

Fig. 1: Reduction of the near-surface porosity by deep rolling of additively manufactured AlSi10Mg samples

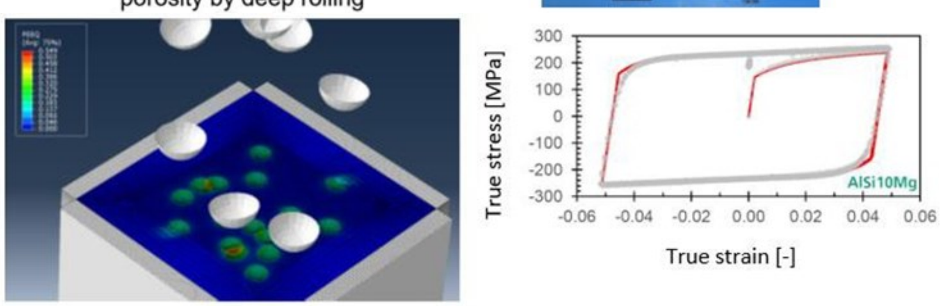

Fig. 2: Simulation of the shot peening process and plasticity model with kinematic hardening for AlSi10Mg material

Abstracts

Laser & Alternative Peening 1

CAVITATION ABRASIVE SURFACE FINISHING AND PEENING (CASF) FOR CLEANING, SMOOTHING AND FATIGUE TREATMENT OF ADDITIVE MANUFACTURED COMPONENTS

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The fundamental science behind the cavitation abrasive surface finishing & peening (CASF) and cavitation water jet peening (CWJP) processes is presented, including how the methodology was derived by emulating the natural weaponry employed by a highly evolved sea creature. These water cavitation technology methods both make use of a very powerful shock wave transmitted through water that is energized from a cloud of imploding water cavitation bubbles as they convert through a phase transformation from the cavitated vapor state back into liquid.

Laser powder bed fusion additive manufacturing (AM) technologies have emerged as a robust and economical manufacturing option for the fabrication of very complex shapes of metal parts. Extraordinary shapes with design features that were never before possible with traditional subtractive manufacturing methods are now routinely produced. CASF has been shown to be particularly effective as a means of removing the build structures and smoothing the surfaces of AM components for the biomedical, aerospace and industrial machinery manufacturing sectors. CASF also has the side benefit of imparting compressive residual stresses for significantly deterring fatigue crack initiation.

Tubular titanium 6Al-4V AM parts externally & internally smoothed and peened with CASF.
Parts are split open in halves for surface roughness and X-Ray diffraction measurements.
Photo: Univ. of Washington, Sugino, Joint Center for Aerospace Technology & Innovation.

Recent progress made for surface finishing AM parts to meet aerospace industrial requirements will be presented, including the smoothing & peening of the inside walls of through holes, trapped cavities, bores and long circuitous passageways within Titanium 6Al-4V shapes.

Traditional surface finishing techniques such as machining, hand working with rotary tools, tumbling, grit blasting, laser ablation and chemical milling with acids have all been applied to remove the unwanted artifacts leftover from the AM build process. However, they all have physical geometric limitations, are sometimes not capable of meeting the engineering requirements, can cause unacceptable defects and can result in defects. The forceful cleaning action of CASF is transferred both line of sight and omni-directionally through the water inside of a processing tank to the part surfaces where the support structure lattices, build stems, partially fused particles, alpha case and other debris are blasted away and the surface is smoothed to bare metal.

CWJP has been demonstrated to reduce the onset of fatigue cracking with benefits that are shown to be similar to that of conventional shot peening. Technical data, measured before and after CASF and CWJP treatment, will be presented for titanium 6Al-4V and CRES 316 wrought test strips. Almen strips treated using the BAC 5730 shot peening processing with the same Intensity Level A as a known reference point have been used as a baseline. Roughness average (Ra) and compressive residual stress results will be shared in order to present a direct comparison of the traditional shot peening and the new cavitation process capabilities.

The CWJP and CASF laboratory processes have been adapted now into multi-axis CNC machines for automated surface finishing of industrial metal products.

EFFECTS OF LASER PEENING ON FATIGUE PROPERTIES OF WELDED ALUMINUM THIN PLATES

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Aluminum alloy thin plates are widely used in transportation machinery such as railway cars. Although friction stir welding (FSW) has become popular as a method for joining thin plates, conventional welding is still widely used. In order to ensure the strength and reliability of transportation machinery, it is essential to improve the strength of welded parts. In this study, an attempt was made to improve the fatigue properties by handheld laser peening (HH-LP) treatment. The material used was A5083-O plate with a thickness of 2 mm, and a heat treatment was applied for annealing. The welded specimens were not cut and joined plates, but were prepared by bead-on TIG welding with argon gas shielding. Laser peening was conducted with a low pulse energy from a HH-LP equipment because the specimens cause warping when conventional laser peening with higher pulse energy is applied.

Fatigue tests were conducted under plane bending fatigue conditions at a load cyclic speed of 1200 cpm and stress amplitudes with R = -1. First, fatigue tests were performed on untreated base material (BM) specimens and the fatigue fracture point was identified. Next, the HH-LP treatment was applied around the fatigue fracture point, and then fatigue tests were conducted to investigate the effect of HH-LP on improving the fatigue properties. The residual stresses (RSs) on the surface after HH-LP were measured by X-ray diffraction (XRD). As a result, the HH-LP treatment gave high compressive RSs over 200 MPa on the surface. The depth of compression was about

0.1 mm from the surface. Because the depth was shallow, the specimen did not warp even when LP was applied to only one side of the thin plate specimens.

As a result of the fatigue test, it was found that the fatigue properties were significantly improved by the HH-LP treatment. Figure 1 shows the S-N diagram of the fatigue test results. The fatigue strength at 107 cycles of the BM specimens was about 100 MPa and that of the HH-LP treated BM specimens was 170 MPa. On the other hand, the fatigue strength of the as-welded specimens was about 70 MPa. The reason why the fatigue strength is lower than that of the BM specimens is the effect of the stress concentration of the weld bead on the center part of the specimens. The stress concentration factor of the weld toe is more than 2 [1]. However, the fatigue strength at 107 cycles was improved by the HH-LP treatment to the same level as that of the BM specimens. The HH-LP treatment made it possible to eliminate the effects of the weld toe.

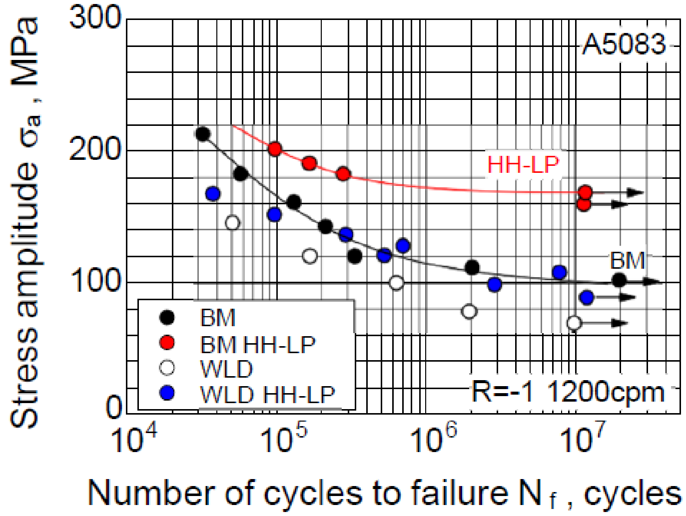

Fig.1 Fatigue results

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EXPANSION OF LASER PEENING APPLICATION WITH A HIGH-POWER MICROCHIP LASER ON A ROBOTIC ARM

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Sebastian Holz, sentenso GmbH
Jörg Behler, sentenso GmbH

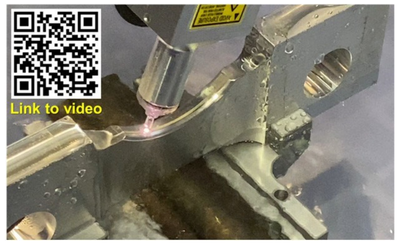
Laser peening (LP) induces compressive residual stress (CRS) in the near-surface layer of metallic components by exposing a water-covered metallic component to successive nanosecond laser pulses from a high-power laser. The resulting CRS has favorable effects in suppressing fatigue crack initiation in load-bearing parts subjected to repetitive loading. However, current LP systems require a high-power laser on a large vibration- isolated optical bench in a clean room facility. Therefore, the application of LP has been limited to indoor production. To expand the horizon of LP, we have developed a prototype of a portable LP device equipped with a palmtop-sized microchip laser.

The device consists of a small collaborative robotic arm holding a microchip laser as an end-effector and a power supply including a water recovery and circulation system. Each part is designed to be small and light enough to be carried as check-in baggage. The device is ready for use immediately after plugging it to a power supply such as a wall outlet and pouring in a few liters of water. Various materials such as steels, nickel-base alloys, titanium alloys, aluminum alloys, etc. have been processed by the prototype and the effect of inducing CRS on the surface and improving fatigue properties has been confirmed. Since the microchip laser is manipulated by the robotic arm, objects with a 3D surface can be precisely processed with the device.

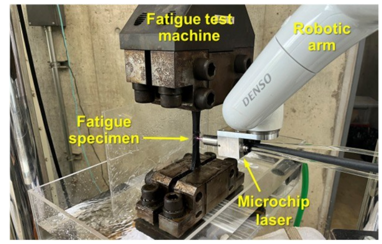
To confirm the outstanding advantages of the portable LP device, an experiment was conducted to simulate its use in a construction site such as steel bridges. Using a fatigue testing machine, a 780 MPa high-strength steel (HT780) specimen was subjected to a tensile preload simulating the dead load of a bridge. The portable LP device was placed next to the fatigue testing machine and the specimen was laser peened without releasing the preload, followed by fatigue testing. Comparison of the fatigue test results with those without preload showed that the fatigue life is significantly extended by the application of preload and subsequent LP.

Tensile stresses on the specimen surface due to preload are converted to compressive by in-situ peening. Fatigue cracks almost always start at the surface. Therefore, in-situ peening is highly effective even though the tensile stress remains inside the component. Until the development of the portable LP device, LP could not be used in such situations. The realization of portable devices has paved the way for these applications.

Portable LP device



Application to 3D specimen



LP of preloaded specimen

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CREATING HETEROGENEOUS SURFACE GRADIENT STRUCTURE VIA ULTRASONIC SHOT PEENING

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Heterogeneous structures remain as one of the most promising applications for recovering the ductility loss that occurs during the strengthening of the material through microstructural alterations. The hybrid functionalization of the regions with different material characteristics leads to superior mechanical responses, surpassing the trade-off between strength and ductility. Mechanical surface treatments have found a very impactful spot in activating the heterogeneous structures as their nature of application causes a significant plastic deformation on the surface along with the adaptation of the microstructure while the core of the material remains unaltered.

Impact-based surface treatments are used as an effective method to reach nanocrystallization on the surface and sub-surface layers. Within this research, ultrasonic shot peening (USP) is applied on tensile test specimens made of 316 austenitic stainless steel. A novel application of localized USP treatment is introduced to enable heterogeneous structures not only through the depth of the material but also through the in-plane surface characteristics. Peened samples are investigated in terms of microstructural analysis and residual stress measurements. Tensile tests are performed to evaluate the strengthening in the samples with different treatment conditions. The results showed that USP is an efficient method to create strong and resilient materials with multifunctional gradients. The novel localized USP approach led to the promising results to create heterogeneous materials.

Abstracts

Shot Peening of Additive Materials 1

THE EFFECT OF FATIGUE STRENGTH ON SHOT PEENED AND BARREL FINISHED SUS316L ADDITIVE MANUFACTURED PRODUCTS

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The metal additive manufacturing process can create shapes that cannot be created with conventional processing methods such as machining. As long as the final shape data is available, it can be processed in anytime and anywhere. In recent years, it has been applied to aerospace parts, medical parts, and molds. The problems with metal additive manufactured products include poor static strength and rough surface. On the other hand, low fatigue strength is confirmed when it is actually used. This is believed to be due to defects that occur during the fabrication process.

Shot peening is expected to increase fatigue strength by work hardening the material surface and introduces compressive residual stress. However, depending on the processing conditions, shot peening may also reduce fatigue strength. This is due to the surface roughness of the peening.

In barrel finishing, the media and product are stirred together in a barrel-shaped container. During stirring, relative motion is generated between the product and the media, and the surface of the product is polished. Therefore, surface roughness is expected to be reduced after barrel finishing. In a previous study, compressive residual stresses were observed to be applied by barrel finishing as well as reducing the surface roughness.

The purpose of this study was to confirm the effect of reducing the roughness by barrel finishing on fatigue strength. Specimens were prepared by laser PBF and shot peening and barrel finishing were applied. Surface roughness, residual stress, and fatigue strength were investigated for each specimen.

As a result, the fatigue strength of the barrel finished specimens was almost same or better than that of the shot peened specimens. The surface roughness of the specimens after barrel finishing was reduced by up to 96% compared to the as built specimens. On the other hand, the surface roughness of the specimens after shot peening was reduced by up to 68% compared to the as built specimens. The increase in compressive residual stress was almost equal to each specimen. Fig.1 shows the residual stress distribution for each specimen. The high compressive residual stresses and low surface roughness of the barrel finished specimens were effective in improving fatigue strength.

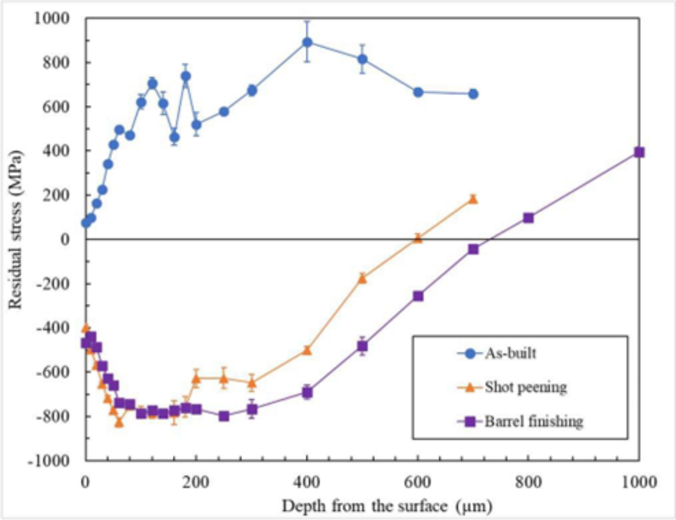

Fig.1 Residual stress distribution

MODULATING MICROSTRUCTURE, SURFACE PROPERTIES AND FATIGUE PROPERTIES OF ADDITIVELY MANUFACTURED AlSi10Mg ALLOY THROUGH PEENING SURFACE POST-TREATMENTS

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Additive manufacturing (AM) techniques have gained significant popularity due to their ability to produce intricate geometries. However, the surface quality of the as-built components often limits their fatigue performance, a consequence of the layer-by-layer construction nature of AM and potential defects due to the complex thermal history. Impact-based surface treatments are considered a strong and viable approach to improve the mechanical properties of the material compared to the as-built state of AM when applied as a post- treatment. This study investigates the effects of shot peening (SP) and ultrasonic shot peening (USP) on the surface characteristics and fatigue behavior of AlSi10Mg specimens produced via laser powder bed fusion (LPBF). An alternative SP treatment, introduced as gradient severe shot peening (GSSP) [1], was applied with varying peening intensities throughout the process. A comprehensive material characterization was performed, focusing on the treated surface morphology and microhardness profile beneath the surface. EBSD analysis was conducted to investigate the in-depth microstructural gradients after the surface treatment and the mechanical performance of the treated materials was assessed through fatigue tests. The results highlight the significant impact of surface treatment on roughness modulation, which positively influenced fatigue resistance. The hardened surface layer and the induced compressive residual stresses also contributed to the increase of the fatigue endurance of the material.

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HYBRID ADDITIVE MANUFACTURING OF POLYLACTIC ACIDE BY FUSED FILAMENT FABRICATION AND SHOT PEENING

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Hybrid additive manufacturing optimizes the mechanical properties of materials by integrating multiple processing techniques. In this study, polylactic acid (PLA) is selected for its economic viability and ease of manufacturability. PLA samples are fabricated using fused filament fabrication (FFF) and enhanced through interlayer shot peening to investigate residual stress development. The combined effects of heat from FFF and plastic deformation from shot peening influence polymer chain orientation and compressive residual stress.

Photoelastic stress analysis is used to quantify these effects, providing insights into how hot and cold working processes modify the residual stress distribution in hybrid additively manufactured PLA.

Abstracts

Laser & Alternative Peening 2

EFFECT OF SHOT AND LASER PEENING ON THE VERY HIGH CYCLE FATIGUE STRENGTH OF ADDITIVE MANUFACTURED MARAGING STEEL

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Additive manufacturing (AM) has recently garnered attention as a novel method for reducing the manufacturing time of metal products. However, defects such as lack of fusion have been observed on the surface and within the material during the AM process, resulting in lower fatigue strength compared with materials created using conventional methods. As metal parts are generally subjected to cyclic loading, the inferior fatigue strength of AM materials represents a significant barrier to expanding their use. Considering the growing demand for extended service life of parts, there is a growing demand for research on fatigue characteristics in the very high cycle fatigue (VHCF). Previous studies have demonstrated that shot peening (SP) and laser peening (LP) enhance the 107 cycles fatigue strength of AM maraging steel. However, these studies did not elucidate the fatigue strength characteristics in the VHCF region exceeding 108 cycles. To address this knowledge gap, the present study was conducted with the objective of investigating the impact of SP and LP on the VHCF strength of AM maraging steel. In this study, ultrasonic fatigue tests were conducted, and the results were evaluated based on the residual stress distribution and defect dimensions.

The test material used was AM maraging steel. Initially, a square bar was fabricated using the PBF-LB/M. The test specimens, with or without a notch, were machined and referred to as smooth and notched specimens, respectively. SP or LP were applied circumferentially around the test section of the specimens. The distributions of residual stress in the depth direction were measured using X-ray method. Ultrasonic fatigue tests were conducted with a frequency of 20 kHz. The results obtained in this study are as follows:

(1) SP exhibited greater compressive stress on the surface compared to LP, while LP exhibited deeper compressive stress than SP. Both SP and LP exhibited tensile stresses on the interior (Fig.1).

(2) The fatigue lives of SP and LP specimens exhibited a significant increase compared to smooth specimens with surface fracture; however, they decreased compared to smooth specimens with internal fracture (Fig.2).

(3) The compressive residual stress suppressed crack growth from the specimen surface. Conversely, tensile residual stress within the material promoted crack growth in VHCF range.

(4) For notched specimens, LP effectively enhanced fatigue strength across a wide range of cycles up to the VHCF regime.

(5) The fatigue strength in the VHCF range can be predicted with a high degree of accuracy using fatigue life prediction equations derived from fracture mechanics.

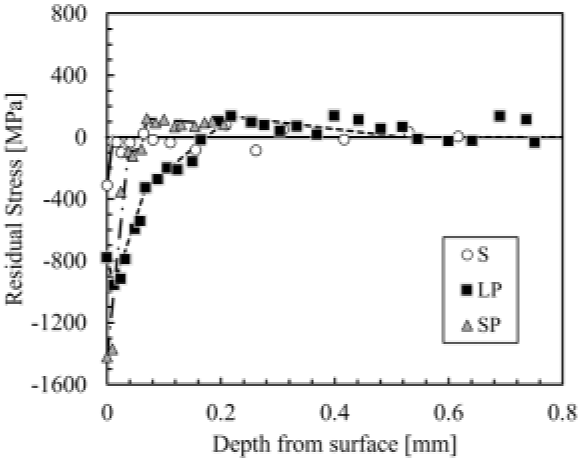

Fig.1 Residual stress distributions in smooth (S), laser peened (LP) and shot peened specimens (SP)

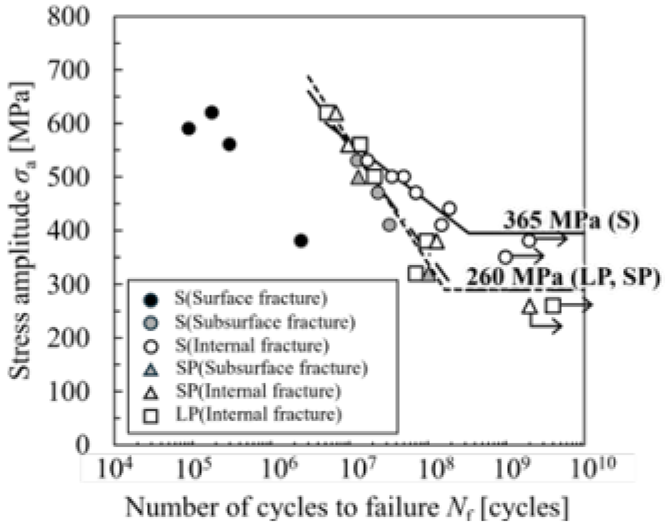

Fig.2 S-N curve for AM maraging steel showing the effects of LP and SP.

PROCESS DESIGN FOR LASER PEEN FORMING OF COMPLEX SHAPE: FROM ANALYTICAL SOLUTION TO PEENING PATTERN

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Laser peen forming (LPF) is a flexible forming process that shapes panels into complex surfaces through thousands of laser shocks spot-by-spot, which is desired in aerospace industries. However, the process parameter design for LPF of complex surfaces is difficult, as it constitutes an inverse problem involving numerous adjustable parameters. Previous efforts have focused on developing empirical, analytical, or optimization-based approaches to obtain approximate solutions, which yielded reasonably satisfactory results but still require further improvement. In this study, we propose a coupled analytical-optimization method for accurate LPF process design based upon our previous work [1, 2]. The complex inverse problem is decomposed into two sub-problems. An analytical-based approach is first employed to determine the eigen-moments that are related to laser parameters, followed by a topology optimization method to obtain the distribution of eigen-moments that is equivalent to peening patterns, significantly reducing the overall design complexity. To validate the proposed method, a double-curved panel with varying curvature is selected as the target surface. The LPF parameters are designed accordingly, and experimental results show conformity between the formed and target surfaces, confirming the effectiveness of the proposed method. This study presents a practical solution for the LPF process design of complex panels with small

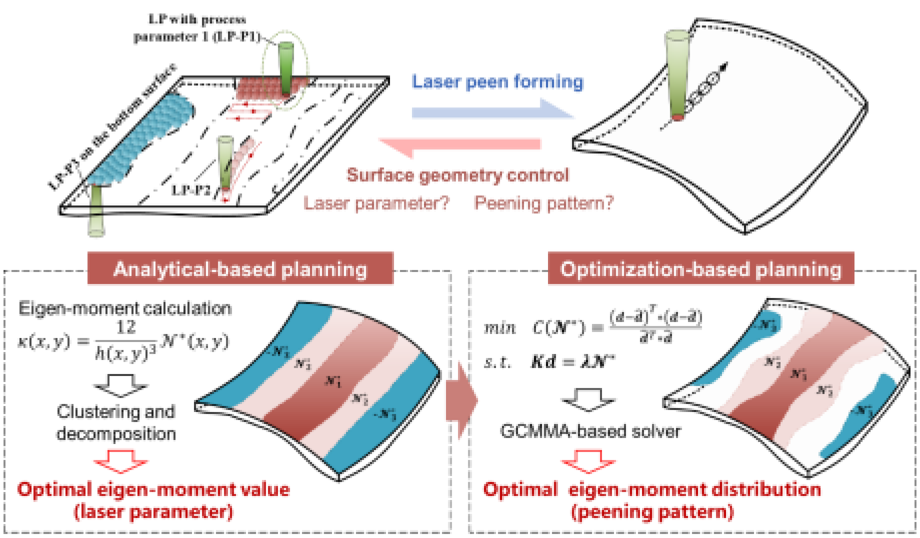

Fig.1 The schematic of the coupled analytical-optimization method for LPF process design: The laser parameters are first defined using an analytical-based method, followed by the determination of peening patterns through an optimization-based method.

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EFFECT OF FINE PARTICLE PEENING INDUCED MATERIAL TRANSFER ON THE INICIAL DEPOSITION BEHAVIOR OF NICKEL ELECTROPLATING ON ALUMINUM SUBSTRATE

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Plating on aluminum surfaces requires a special pretreatment called zincate treatment, which is a complicated procedure. Fine Particle Peening (FPP), in which particles with a diameter of 200 μm or less bombard the surface to be treated, has attracted attention as an alternative means of implementing pretreatment for plating because it can add particle components to the surface by transferring the particle fragments. This method has the potential to enhance deposition as well as adhesion at the plating interface. In a previous study, plating on aluminum substrate peened with steel particles was verified to promote deposition. The purpose of this study is to investigate whether FPP is effective as a pretreatment by examining the initial deposition behavior of nickel electroplating. Steel particles and glass particles were employed to perform FPP on A1050-H24, a commercial pure aluminum specimen. Comparisons were made under three different conditions, including the unpeened specimen, focusing on the effects of transfer and crystal grain refinement due to differences in projected particles. The specimens peened with steel particles exhibited a specific microstructure with an exclusive distribution of iron and aluminum phases, forming a lamellar microstructure. The surfaces of the specimens were then polished to planarize the peened surface with maintaining the modified layer by FPP. This was done to eliminate the effects of unevenness and to facilitate EBSD analysis. EBSD measurements of the planarized FPP specimens showed that the Aluminum phase of the FPP-treated specimens was finer than that of the untreated specimens, with crystal grains approximately one-hundredth the size of those in the untreated specimens. This is due to the alteration caused by FPP. The polishing process also exposed the fabricated modified layer. Next, electrolytic nickel plating was performed on aluminum substrates that had undergone FPP using either steel or glass particles followed by pickling in the nitric acid. After electrodeposition, a large amount of nickel was precipitated in the iron-deposited areas. In the specimens peened with glass particles, aluminum and silicon-containing phases were exposed. The silicon-containing phase is considered to be attributed with embedded glass particles. Nickel deposition was lower in the electrodeposited specimens than in the specimens peened with steel particles. This implied that the transferred component encouraged the initial deposition.

NUMERICAL ASSESSMENT OF SHOT PEENING CONTRIBUTION TO THE FATIGUE STRENGTH OF GEAR TOOTH ROOT

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Fatigue failure is a major concern in gears due to the cyclic loads they endure during operation, particularly in high-performance applications where reliability and service life are critical. To mitigate fatigue damage, various surface treatments are applied to enhance mechanical properties. However, their contribution is often considered conservatively based on standardized approaches, limiting their optimized application in industrial components.

Shot peening (SP) is well known for inducing beneficial compressive residual stresses that improve fatigue resistance. However, its combined effect with case-hardening remains insufficiently explored. This study numerically simulates the SP treatment to evaluate the influence of SP on the fatigue strength of raw and case- hardened gears subjected to single-tooth bending fatigue (STBF) conditions.

The case study focuses on a spur gear, commonly used in automotive and heavy machinery industries. Four conditions are analyzed: (i) untreated, (ii) case-hardened, (iii) shot-peened, and (iv) case-hardened and shot- peened. A numerical model simulates the residual stress fields from both treatments, ensuring a realistic mechanical representation.

Multi-axial fatigue criteria in combination with the theory of critical distances (TCD) are applied under different loading conditions to assess their effects. The results confirm that SP significantly enhances fatigue strength by inducing compressive residual stresses that delay crack initiation and slow propagation. When combined with case-hardening, SP further improves fatigue resistance, revealing a strong synergistic effect.

These findings highlight the need for an optimized surface treatment strategy beyond conventional design methodologies. This study provides valuable insights into fatigue life improvement in shot-peened and case- hardened gears, contributing to the development of more durable and efficient industrial components.

THE IMPACT OF SURFACE FINISH TREATMENTS ON THE FATIGUE STRENGTH OF SHOT PEENED AL ALLOYS

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Shot peening treatments, particularly those employing high coverage and large shots, often induce significant roughening of the treated surface on Al alloys. This study investigates the influence of surface finish on the fatigue strength of Al-7075-T6 subjected to two types of shot peening treatment. The first treatment utilized large ceramic shots (Z425), while the second involved a double peening approach combining Z425 with a smaller shot and high coverage treatment (Z100 1000%) aimed at inducing grain refinement in the surface layers. After shot peening, surface finish treatments at various finishing depths were applied to identify the most effective one for enhancing fatigue strength. Surface layer modifications were evaluated through surface profile, in-depth microhardness, and residual stress profile measurements. Fractographic analysis revealed a tendency for crack initiation below the surface layers affected by the treatments. Fatigue strength predictions were successfully achieved using an average strain energy density approach developed in [1,2] that considered the influence of compressive residual stresses and the sub-superficial crack initiation site.

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INVESTIGATIONS ON THE FATIGUE STRENGTH OF THREADS PRODUCED BY DIFFERENT FABRICATION TECHNIQUES

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Sustainability is playing an increasingly important role in modern product development. The need for durable, high-quality components is emphasised in order to reduce the consumption of resources and energy and thus the environmental impact over the life cycle of a product. Not only the component in use but also its manufacturing route must be taken into account. In this study, the effects of different thread manufacturing processes (cutting, rolling and deep rolling) on the fatigue strength of threads are investigated.

Cylindrical samples made of 42CrMo+QT with M12 threads at both ends were analysed. Fatigue tests were carried out under cyclic tensile loading and analysed in accordance with DIN 50100. In addition, quasi-static tensile tests were carried out to determine the material characteristics. Metallographic investigations, hardness and residual stress depth distributions were carried out to characterise the near-surface condition of the thread after the various manufacturing processes.

To summarise, the study showed that thread rolling leads to the highest fatigue strength and durability, which underpins its position as the optimum manufacturing process. However, deep rolling offers a viable alternative to alternative to improve fatigue properties, especially for lower volume applications where traditional rolling is less economical.

OPTICAL PROFILOMETRY FOR MEASUREMENT OF RESIDUAL STRESS VARIABILITY

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The resultant compressive residual stress field is key to the improved fatigue performance achieved through shot peening. Experimental techniques such as X-Ray diffraction and hole drilling are commonly used to measure and verify the average stress field near the surface of the component. While reliable, the spatial resolution of these measurements are coarse in comparison to the isoeffect region of a single impact, meaning they are not suited toward inferring small-scale fluctuations in residual stress. Commonly used in quantifying surface roughness, optical profilometry provides high-resolution, sub-impact scale, projections of the surface that can be manipulated in the form of point clouds. This report details the application of the two-dimensional Fourier transform to create smoothed reconstructions of peened surfaces, leveraging harmonic analyses to infer localized fluctuations in residual stress. Verified against mean field residual stress measurements with X-Ray diffraction and representative elementary volume finite element simulations.

OVERCOMING THE CHALLENGES OF ROBOTIC SHOT PEENING WITH ADAPTIVE AUTOMATION

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Manufacturers increasingly struggle with robotic shot peening as production shifts toward high-mix, high variability manufacturing. Traditional robotic systems require time-consuming, manual programming, often taking days or weeks to accommodate complex geometries. Additionally, these systems lack adaptive capabilities, making it difficult to compensate for part variations—leading to costly manual touchups, inefficiencies, and production delays.

Augmentus transforms robotic shot peening by combining advanced 3D scanning with automated toolpath generation. By eliminating the need for manual programming and enabling seamless adaptation to part variations, Augmentus ensures greater accuracy, reduced rework, and significantly improved operational efficiency.

This presentation explores how Augmentus overcomes key industry barriers, empowering manufacturers with precision, adaptability, and unmatched process efficiency in robotic shot peening.

EFFECTS OF SPRING SHAPE, RESIDUAL STRESS AND HARDNESS BY STRESS RELIEVING HEAT TREATMENT OF COLD- FORMED SPRINGS

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The purpose of this study is to confirm the change in spring shape, residual stress distributions, and material hardness values after the stress relief heat treatment conditions to the cold-formed springs, which apply to automobile suspension systems. The acquired data can be used to improve the design technology for springs considering change in shape and physical properties, and evenly optimizing heat treatment process conditions. Changes in shape elements such as the maximum outer diameter of the spring, total number of coil turns, and free height were measured according to the temperature and time conditions of stress relief heat treatment. Additionally, the degree of relaxation of residual stress on the inner and outer surfaces of the coil was confirmed, and the corresponding change in hardness value was confirmed. Finally, the meaning and its usability of the study will be discussed in practical point of view.

ADAPTATION OF SHOT PEEN PARAMETERS FOR GEAR GEOMETRY

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Beth Matlock, TEC Materials Testing

Shot peening is a well-established process for the surface enhancement of gearing. Gearing is a primary example of a high cycle fatigue application that can benefit from residual stress enhancement. Designing shot peening parameters to specific gear geometry based on material, heat treatment, and surface finish is a more precise way to achieve better performance outcomes. One of the best tools to assist in the optimal shot peening is x-ray diffraction (XRD) and its ability to measure small differences that can result in significant performance outcomes. XRD residual stress measurements are a direct measurement of elastic strain. The diffraction peak width is an indication of plastic strain and is also proportional to the hardness of steels. Together, the elastic and plastic strain information provides tremendous insight into the condition of a shot peened gear.

This paper will review a wide variety of gear geometry and their various heat treatments and surface finishes. The discussion will encompass how the shot peen parameters can be modified based on the physical characteristics of the gear and also the failure mode. X-ray diffraction results will be provided to supplement the discussion.

DRY LASER PEENING: A NEW LASER PEENING TECHNIQUE WITHOUT BOTH COATING AND WATER USING FEMTOSECOND LASER-DRIVEN SHOCK WAVE

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Introduction

Dry laser peening enables improving fatigue performance of metallic materials using femtosecond laser pulses without a sacrificial overlay in air [1-7]. The intensity of a femtosecond laser pulse is extremely high even at a low energy because the pulse width is extremely short. Therefore, direct irradiation of a solid surface with a femtosecond laser pulse drives an intense shock wave that propagates into the solid. Such a shock wave driven by the femtosecond laser pulse irradiated under atmospheric conditions deforms a material plastically. Heat affected and melted zones formed by a femtosecond laser pulse are much smaller than those produced by a nanosecond laser pulse due to its extremely short pulse width. Therefore, peening without a sacrificial overlay in air is possible using femtosecond laser pulses.

Objective

The objective of this study is to verify the effectiveness of the dry laser peening for laser-welded 2024 aluminum alloy containing welding defects by investigating the mechanical properties.

Methodology

The material used in this study was a laser-welded precipitation-hardened 2024 aluminum alloy which is commercially used in the aerospace industry. Femtosecond laser pulses (Spectra-Physics Inc., Spitfire) with a wavelength of 800 nm and a pulse width of 120 fs were focused using a plano-convex lens and irradiated normal to the electropolished surface of the specimen in air. The surface morphology and microstructure were observed and its mechanical properties such as hardness, residual stress, and fatigue properties were measured to evaluate the peening effects.

Results

Before the dry laser peening treatment, the hardness of the base material was 138 HV, while that on the surface of the weld metal was ~100 HV. This decrease in hardness was due to Mg (which is required for precipitation strengthening) being vaporized during welding, resulting in fewer precipitates being formed, even after natural aging for 15 months. The hardness of the HAZ in this specimen was around 130 HV (similar to the BM), because of the dissolution of precipitates and grain coarsening. After the dry laser peening treatment, the hardness of all areas of the sample increased compared to that of the as-welded sample. The hardness of the weld metal was similar to that of the base material before peening, while the hardness of the heat affected zone and base material after the dry laser peening treatment was around 178 HV.

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Shot Peening of Additive Materials 2

IMPROVEMENT OF THE FATIGUE BEHAVIOUR OF ADDITIVE MANUFATURED SCALMALLOY BY USING SURFACE IMPROVEMENT PROCESSES

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Alejandro Muñoz, Curtiss Wright Surface Technologies, Metal Improvement Company LLC

The use of light metals such as Aluminum alloys has experienced a remarkable increase for the additive manufacturing (AM) industry, especially in aerospace. Soviet scientist developed the first scandium – containing alloys, and then, decades later, Airbus engineers came up with a second-generation alloy called Scalmalloy®.

AM Scalmalloy (an Al-Mg-Sc alloy) shows outstanding behavior with much higher mechanical performance with respect to other alloys for powder bed fusion laser-based (PBF-LB) process like AlSi10Mg or AlSi7Mg. Recent studies have mainly focused on static loading, with minor attention to cyclic loading despite its vital importance in many applications.

In this work, the fatigue performance of PBF-LB Scalmalloy was investigated considering the effects of surface improvement processes to identify the set of optimal post-processes to be applied. Shot peening with steel and glass balls, laser peening combined with C.A.S.E. (chemically assisted surface enhancement) treatments were initially selected. After developing the state of the art, and thanks to the previous experience in the application of surface treatments of the company Curtiss Wright Surface Technologies, Metal Improvement Company LLC the optimal parameters for each of the surface treatments has been selected. Residual stress measurements using blind hole drilling methods have been included to obtain a depth profile of the residual stress and to analyze the stress effect of each surface treatment. Tensile and fatigue tests were also performed for each surface treatment. Shot peening treatment with steel balls + C.A.S.E. has allowed to significantly improve the fatigue life of the Al- Mg-Sc parts, reducing internal defects and roughness, thanks to the generation of a favorable residual stress field. Afterwards, the treatments were validated in an optimized AM demonstrator.

The correct identification of post-processes has allowed to expand the range of AM applications, and specifically of the Scalmalloy® for load-bearing components in the aerospace sector, providing a clear benefit of weight reduction associated with their operation in service, guaranteeing an adequate useful life for them. Additionally, this work demonstrates the effectiveness of surface treatments on improving the properties of AM components, analyzing possibilities of technological transfer to other sectors such as naval, civil engineering, automotive or medicine, among others.

COMPARISON OF PEENING EFFECT BETWEEN ADDITIVE MANUFACUTRED AND DRAWING TITANIUM ALLOY

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Additive manufactured (AM) metallic materials are attractive materials, as a shape is generated from CAD/CAM data directly and an optimum shape in topologically can be produced. However, fatigue strength *sf* of as-built (AB) AM metals is nearly half of drawing metals, as the surface of AB specimen is considerably rough due to partially melted particles. Mecahical surface treatments such as shot peening (SP), submerged laser peening (SLP) and cavitation peening (CP) can enhance *sf* of AB AM metals [1-3]. In the present paper, mechanical surface treatments were proposed to enhance *sf* of AB AM metals, and the comparison of peening effect between AM metal and drawing metal was discussed.

Figure 1 and Table 1 show S-N curves and *sf* for drawing Ti6Al4V and AM Ti6Al4V treated by SP, SLP, CP, fine particle bombarding process (FPBP) and hydrodynamic cavitation abrasive finishing (HCAF) comparing with non-peened (NP) drawing and AB PBF-LS. In Fig. 1, AM Ti6Al4V was manufactured by powder bed fusion using laser sintering PBF-LS [2,3]. The fatigue properties were investigated by a torsional fatigue tester which was developed to evaluate AM metals [4]. The applied shear stress was normalized by *sf* of NP drawing Ti6Al4V at *N* = 107, i.e., 347 ± 26 MPa, which was obtained by Little's method [5]. In Table 1, relative *sf* which was calculated by using *sf* of NP drawing and AB PBF-LS was also revealed.

Obtained results were follows. The *sf* of AB PBF-LS was about 60 % of NP drawing, *sf* of SLP, FPBP and FPBP+CP of PBF-LS were larger than NP drawing. Relative *sf* of SP and LP of PBF-LS was larger than that of drawing specimen. Namely, peening effect on PBF-LS was larger than that of drawing

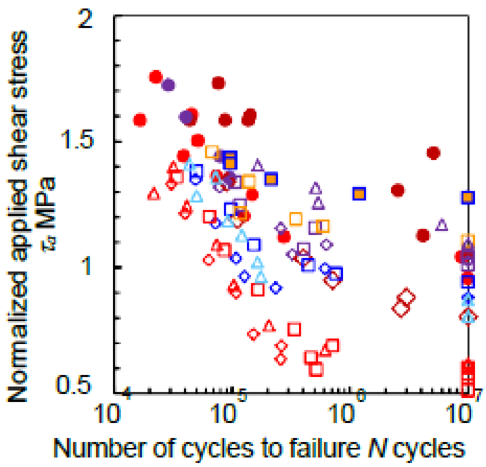

Fig. 1 S-N curves of tested Ti6Al4V

Table 1 Fatigue strength σ_f of tested Ti6Al4V

Symbol	Material	Treatment	σ_f [MPa]	Normalized σ_f	Relative σ_f
●	Drawing	NP	347 ± 26	1	1
●		SP	379 ± 22	1.09	1.09
●		SLP	457 ± 22	1.32	1.32
◇	PBF-LS [2]	AB	217 ± 7	0.63	1
◇		SLP	361 ± 8	1.04	1.66
◇		CP	313 ± 11	0.90	1.44
◇		SP	285 ± 10	0.82	1.31
□	PBF-LS	AB	210 ± 10	0.61	1
□		CP	333 ± 10	0.96	1.59
□		SLP	359 ± 9	1.03	1.71
□		FPBP	393 ± 18	1.13	1.87
□		FPBP+CP	446 ± 5	1.29	2.12
△	PBF-LS [3]	AB	224 ± 16	0.65	1
△		SLP	393 ± 22	1.13	1.75
△		HCAF	324 ± 25	0.93	1.45

Acknowledgments

This work was partly supported by JSPS KAKENHI (22KK0050 and 23K25988) and JST CREST (JPMJCR2335).

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MITIGATION OF HYDROGEN EMBRITTLEMENT IN INCONEL 718 PRODUCED BY LPBF USING SHOT PEENING

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Context and objective

Shot peening is a widely used surface treatment in industry, aiming to enhance the fatigue life of ductile metal structures [1–4]. By impacting metal surfaces with high-velocity microshots, it induces beneficial surface plastic deformations. Notably, recent research has shown that shot peening can effectively mitigate and even eliminate Hydrogen Embrittlement in steel and aluminum alloys under monotonic loading [5,6]. A key finding by Wang et al.[6] highlighted that prolonged shot peening times can completely eradicate HE. Despite this progress, the effectiveness of shot peening on Additively Manufactured Inconel 718 remains unexplored.

The primary objective of this study is to assess the effectiveness of shot peening in reducing hydrogen embrittlement in Inconel 718 components manufactured using laser powder bed fusion (LPBF).

Methodology

To assess the efficacy of shot peening in reducing Hydrogen Embrittlement, ductility will be evaluated through slow strain rate tensile tests at 10-5 s-1, allowing for hydrogen diffusion within the samples. The test matrix comprises:

- 3 shot-peened and hydrogen-saturated specimens
- 3 shot-peened and non-hydrogenated specimens
- 1 non-shot-peened and hydrogenated specimen
- 1 non-shot-peened and non-hydrogenated specimen

Microstructural and fractographic characterizations will be performed to analyze the tensile test results. Finally, Thermal Desorption Spectroscopy will quantify the hydrogen content before and after shot peening.

Futures results

With all specimens currently ready for evaluation, the mechanical testing phase is slated for February. Following this, in-depth characterizations and analyses will be conducted to unveil the project's key findings.

INFLUENCE ON SHOT PEENING AND BLAST POLISHING FOR ROTATING BENDING FATIGUE STRENGTH OF VACUUM CARBURIZED STEEL WITH CIRCUMFERENTIAL NOTCH

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Downsizing of automotive gear is required in order to improve of a fuel efficiency since before. The strengthening of fatigue strength for a carburized gear is important for downsizing because of the increasing applied stress against gear tooth due to the smaller tooth width by downsize of it. Shot peening is one of enhance method for increasing fatigue strength. In the case of Japanese transmission supplier, the transmission gear has been being downsized by applying dual shot peening which is combination of conventional shot peening and fine particle shot peening. In recent year, further strengthening of fatigue strength for carburized gear is required in order to downsize of it for a reduction gear unit of electric vehicle. In this study, we investigated the influence on the combination of shot peening and blast polishing for fatigue strength of vacuum carburized steel.

JIS SCM420 steel which is vacuum carburized was applied as test material. The shape of specimen was round bar specimen of minimum diameter 5mm which has circumferential notch. Dual shot peening which is combination conventional shot peening and fine particle shot peening was performed to the specimen. Blast polishing which is polishing method by air blasting used resin media contains abrasives was performed to some shot peened specimen. There are 2 blast polishing conditions which was varied amount of surface removal.

The amount of surface removal was 10μm and 50μm. The kinds of specimens were 4 conditions which were non-peened specimens, dual shot peened specimens, blast polished (10μm removal) specimens and blast polished (50μm removal) specimens. The rotating bending fatigue test was conducted against these specimens. As a result, the fatigue strength of carburized steel was increased by shot peening and combination of shot peening and blat polishing. Especially, blast polished (10μm removal) specimen was best condition to increase fatigue strength. The fatigue strength of blast polished (10μm removal) specimen was twice comparison with that of non-peened specimen. The reason of increasing fatigue strength of blast polished (10μm removal) specimen was to inhibit fatigue crack initiation and fatigue crack propagation due to smooth surface and high compressive residual stress below surface due to the blast polishing after dual shot peening.

EFFECT OF HARDNESS AND RESIDUAL STRESS ON ROLLING CONTACT FATIGUE LIFE OF DUCTILE IRON

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This study investigates the rolling contact fatigue (RCF) behavior of ductile iron (DI) using experimental and analytical method. The behavior of DI was assessed under both torsion and RCF loading environments. RCF performance was assessed using a 3 ball-on-rod test setup at a Hertzian contact pressure of 3.6 GPa. Torsion fatigue tests were carried out using an MTS torsion test setup to obtain the material's stress-life (S-N) response. The mechanical properties of DI were thoroughly characterized, including global hardness (Rockwell) and matrix hardness (nano-indentation). Nano-indentation also assessed hardness distribution with depth in RCF-tested rods. X -ray diffraction (XRD) analysis, conducted before and after RCF testing, revealed a 31.8% increase in compressive residual stress. To further validate the experimental findings, a continuum damage mechanics finite element (CDM-FE) model was employed for fatigue life prediction. The material constants used in the damage evolution equation of the CDM framework were obtained using torsion fatigue S-N data. Different residual stress profiles along the depth of the material were incorporated into the model, and the corresponding RCF life predictions were compared. The analytical results demonstrated strong corroboration with the experimental data, confirming the significance of residual stress in influencing fatigue performance. A two-parameter Weibull distribution was utilized to characterize the DI material's probability of failure, demonstrating that its RCF performance is comparable to that of high-strength bearing steel.

ENHANCING HIGH CYCLE FATIGUE PERFOMANCE OF ELECTRON BEAM MELTED TI6AL4V: A STUDY ON SHOT PEENING AND HOT ISOSTATIC PRESSING

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The qualification of metal Additive Manufacturing (AM) for safety-critical applications is hindered by variability in mechanical properties, particularly in high cycle fatigue performance (HCF). For electron beam powder bed fusion (PBF-EB) Ti6Al4V, surface roughness and process-induced defect significantly impact fatigue resistance, necessitating effective post-processing treatments to improve cyclic performance. However, conventional post- processing techniques such as the hot isostatic pressing have demonstrated limited effectiveness in mitigating surface-related fatigue failures in as-fabricated PBF-EB specimens. This study investigates the role of PBF-EB- specific post-processing to enhance the HCF performance of PBF-EB Ti6Al4V, providing a pathway toward achieving mechanical properties comparable to cast and wrought alloys.

The influence of a novel low-temperature HIP treatment combined with shot peening (CW35 shot peen media at 0.006-0.01A intensity) on PBF-EB Ti6Al4V was explored in this study. A total of 22 specimens fabricated in the vertical and horizontal orientation underwent high cycle fatigue testing per ASTM E466. X-Ray microcomputed tomography showed a significant decrease in the internal defect distribution, which successfully removed the largest defects. Surface roughness characterization showed a change in the machined surface after shot peening, with a reduction in the average valley depth and a more uniform surface as the skewness decreased. The application of shot peening thus led to an enhancement in fatigue performance by introducing compressive residual stresses and delaying crack initiation. The combined HIP and shot peening treatments resulted in an increase of 100 MPa in the fatigue strength of PBF-EB Ti6Al4V, compared to the machined-only specimens.

This study highlights the critical role of surface modification in extending the fatigue life of PBF-EB Ti6Al4V and emphasize the necessity of integrating optimizing post-processing strategies for metal AM components.

Abstracts

Industrial Applications 4

FROM STRAIN TO STRESS: STRESS MAP TESTING OF ALMEN STRIPS

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Almen strips have long been used to evaluate shot peening intensity, with arc height serving as a key indicator of saturation. Arc height is a measure of strain in the material. In cases of oversaturation, arc height measurements become less informative, even as internal stresses continue to evolve. Stress mapping tests (SMT) in this work involve the controlled flattening of an Almen strip onto a spatial pressure sensor, acting as an inferential measurement for the net bending moment. Stress mapping is related to Almen strip intensity measurements via first-principles mechanics and beam theory and can be verified by XRD residual stress profiling. The work will explore how stress mapping tests can provide additional insights into the internal stress state of Almen strips, potentially offering a faster and more practical alternative to full residual stress depth profiling. This framework provides a fundamental understanding of how internal stresses develop beyond what strain height alone reveals. If first-principles approaches prove insufficient, empirical correlations between SMT results and residual stress profiles will be explored as a secondary approach. We aim to bridge the gap between stress mapping, oversaturation effects, and residual stress, with implications for both scientific understanding and industrial applications.

STRUCTURE-PROCESSING-MECHANICAL PROPERTY MEASUREMENTS USING HIGH-THROUGHPUT NANOINDENTATION

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Nanoindentation is an ideal technique to measure localized elastic and plastic properties of materials. When automated for high throughput, it enables the characterization of heterogeneous property distributions with high spatial resolution in both depth and lateral directions. This capability is uniquely suited for quantifying and visualizing structure property relationships resulting from surface hardening treatments, heat affected zones from processing, damage gradients from environmental exposure, and multi-phase microstructures.

Recent innovations have enabled numerous new testing methodologies and control algorithms, which will be highlighted here. One such mode utilizes triggers for high-throughput surface detection, enabling precise spatial mapping under displacement control. This approach ensures tight indentation spacing by maintaining consistent indentation depth, preventing neighboring indents from interacting with each other, even in materials with significant phase hardness variations. This method can be applied across a wide range of scales, from sub- micron to millimeter dimensions. Additionally, these tests can be easily correlated with structural and chemical data when utilizing the PI89 Auto in situ SEM indenter. Another significant application is depth control while performing creep and frequency sweep dynamic measurements in thin films, which mitigates substrate effects that could compromise the results.

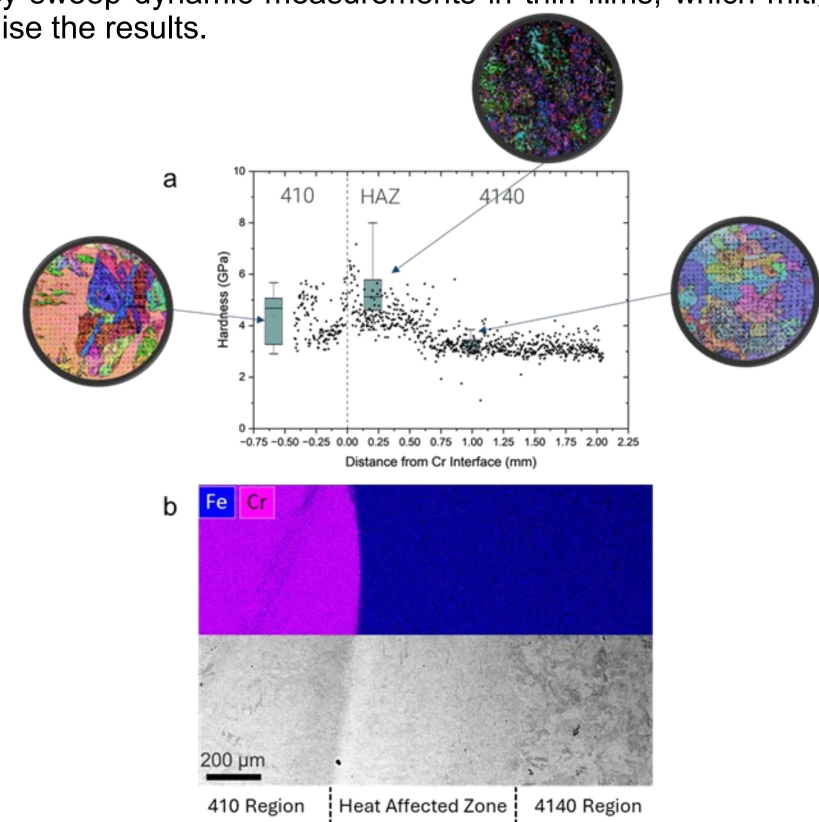

Figure 1: Correlated (a) hardness data and (b) chemical information/SEM imaging from the PI89 Auto. The sample is a laser cladding of 410 stainless steel onto 4140. The circular insets show an example grain orientation map from 3 distinct microstructural regions. A clear rise in hardness is observed in the heat affected zone from the cladding process. The 410 exhibits a bimodal hardness distribution due to its mixed microstructure of tempered martensite and ferrite.

INVESTIGATION OF TOPOGRAPHY CHANGES OF BLASTED SURFACES: AN EXPERIMENTAL PERSPECTIVE USING FIDUCIAL MARKERS

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Abrasive blasting is used to modify the surface topography with a variety of objectives, such as cleaning, roughening, creating an optical appearance or inducing residual compressive stress, as in shot peening. The surface topography is altered directly by the impact of the blast media. The change in topography can be observed by surface measurements before and after the manufacturing process. Due to the limited part of the surface to be measured compared to the whole surface, it is not possible to find the exact same spot without a unambiguous reference. This is where fiducial markers can be used. However, the challenge is that the marker must remain unchanged by the subsequent manufacturing process.

The paper presents a process using fiducial markers protected by a custom 3D printed cover. The markers are multiple indentations made by a Vickers hardness indenter. This makes it possible to observe the changes caused by the blasting process at the same location and how the topography evolves over time. It is shown for a smooth milled initial surface. Figures 1 a and b show an example of this initial surface and the surface after 10 minutes of blasting using a patented wheel blast machine without compressed air and a spherical abrasive.

Using the fiducial markers, it is possible to superimpose the surfaces (see Figure 1c). The difference between the initial surface and the resulting surface shows the dents (in dark grey) and the bulging of the material (in white (Figure 1d).

In addition, the effect on a rougher additively manufactured initial surface is shown for the difference between the initial surface and a blasting time of 10 minutes. It can be seen that the blasting removes the adherent particles and also the dents and bulges added to the surface.

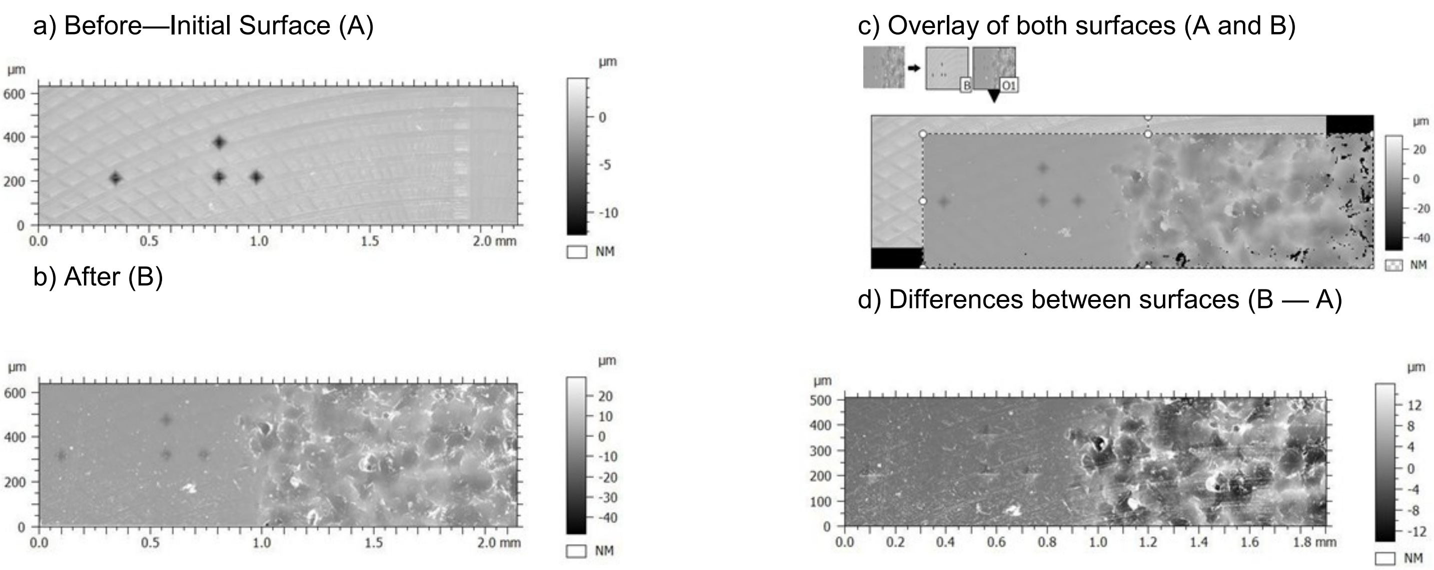

Figure 1: Evolution of surface topography by blasting and evaluation

In summary, a method using fiducial markers and a 3D printed cover is demonstrated that can be used to experimentally investigate topography changes due to manufacturing processes. The method has been used to observe the blasting process on a milled surface for a number of times, and also exemplarily for an additively manufactured surface.

IMPROVEMENT OF LITHIUM-METAL ELECTRODE ALL-SOLID-STATE BATTERIES PERFORMACE BY SHOT PEENING AND MAGNETRON SPUTTERING

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To achieve a carbon neutral society, gasoline-powered vehicles must be switched to high performance electric vehicles (EVs). All-solid-state lithium-metal batteries (ASSLiMBs) are a candidate technology of the battery for the high-performance EVs, due to their high capacity for long cruising distance and high safety. However, the charging speed of the ASSLiMBs with oxide-based solid electrolyte is not sufficient for EV. This limitation in charging speed is due to the restricted current density during charging. If the current density is too high, the battery may fail by internal short circuits caused by the growth of lithium dendrites. Lithium dendrites grow from the uneven lithium deposition, with is caused by localized increases in current density resulting from poor contact between the solid electrolyte and lithium metal, where the dendrites originate. The fracture toughness of an oxide-based solid electrolyte was confirmed to increase through shot peening for its surface. The increased fracture toughness of the solid electrolyte surface physically suppresses the growth of lithium dendrites because the crack propagation is less likely under stress concentration on the solid electrolyte caused by the non-uniform deposition of lithium. Shot peening on oxide-based solid electrolytes has a synergistic effect with Au sputtering. Au sputtering forms a thin Au film on the surface of solid electrolyte after shot peening and can reduce interface resistance and promote uniform interfacial reaction by interposing Au intermediate layer between solid electrolyte and lithium metal. It has been reported that the combined use of shot peening and Au sputtering can increase the charge rate compared to the case without processing [1]. Fig. (a) shows schematic diagram of the effect on the interface of normal sputtering and magnetron sputtering after shot peening. A problem usually encountered with normal sputtering is the reduction in fracture toughness due to contact of the high-temperature plasma with the surface of the solid electrolyte. In this study, we focused on magnetron sputtering. Magnetron sputtering, in which the toroidal plasma is densely arranged near the target metal by magnetic pressure, can dilute the plasma on the surface of the solid electrolyte, enabling low-damage Au sputtering. We fabricated cells with solid electrolytes that underwent either conventional sputtering or magnetron sputtering after the shot peening process and evaluated their performance. Fig. (b) shows critical current density (CCD) under each sputtering condition. The results showed that after shot peening, the charging performance was better when magnetron sputtering was used compared to normal sputtering was used. The fracture toughness of the surface of the sputtered solid electrolytes produced via normal and magnetron sputtering was also measured for each Au thickness after shot peening. The results showed that the decrease in fracture toughness was suppressed when magnetron sputtering was used compared to the use of normal sputtering. This indicates that the synergistic effect of shot peening, which increases fracture toughness, and magnetron sputtering, which interposes the Au intermediate layer without reducing fracture toughness, can further improve the charging performance of ASSLiMBs with oxide-based solid electrolyte.

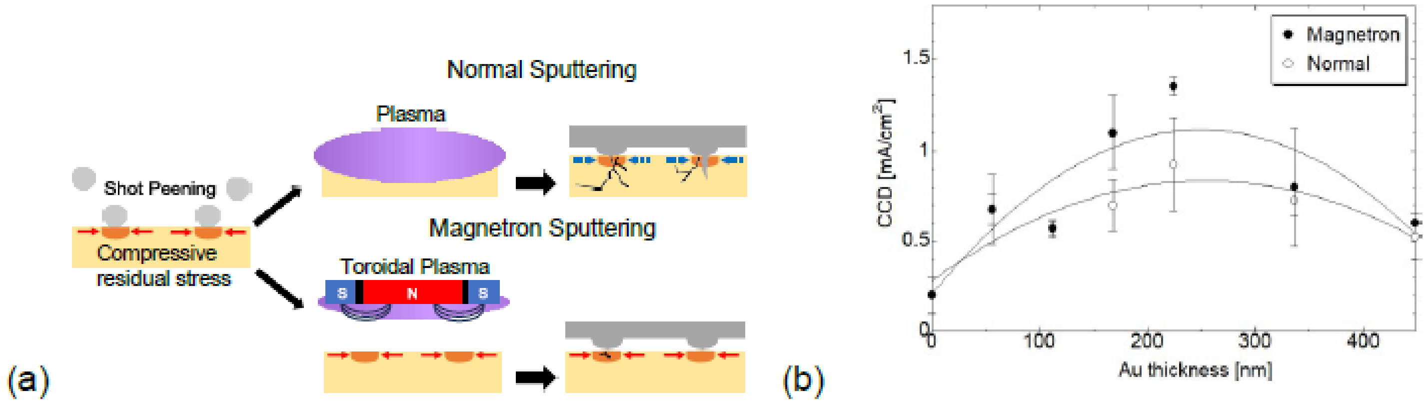

Fig. (a) Schematic diagram of the effect on the interface of normal sputtering and magnetron sputtering after shot peening, (b) critical current density (CCD) under each sputtering condition

Reference

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PEENING COVERAGE EFFECTS ON SURFACE INTEGRITY OF ADDITIVE MANUFACTURED 316SS

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Additive manufacturing (AM), particularly laser-powder-bed-fusion (LPBF) is increasingly used to fabricate high- performance automobile components such as fuel nozzles and heat exchangers. This is primarily due to AM's ability to produce intricate geometries with enhanced design flexibility. However, the high roughness in as-printed parts degrades mechanical performance. Additionally, large residual (tensile) stresses develop due to steep thermal gradient caused by localized heating and rapid cooling during LPBF process.

Shot peening, a surface work-hardening technique, is an effective post-processing method to address these challenges. Specifically, the research objective is to understand the surface homogenization effect through material redistribution by inhomogeneous elastic-plastic deformation across surface orientations (0−90°) in 316SS LPBF parts. Among shot peening parameters, coverage is optimized in this study to mitigate orientation- dependent surface properties in LPBF 316SS. Coverage is critical as it ensures uniform treatment of entire surface and enhances the depth of induced effects. At the maximum analyzed coverage (1000%), the as-printed roughness is reduced by ≈ 35% throughout orientations (0−90°). Additionally, transforms the tensile residual stress (≈ 50 MPa) to significantly compressive (≈ −400 MPa). Roughness reduction reaches saturation at 800% coverage, with further increase providing negligible improvement. These findings establish coverage as a key parameter in tuning surface integrity and highlights the immense enhancement of AM components through shot peening.

ANISOTROPIC RESIDUAL STRESS MEASUREMENTS IN ADDITIVELY MANUFACTURED 316 STAINLESS STEEL PARTS

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Additive manufacturing (AM) is increasingly used to produce complex parts for industries like aerospace and medical devices. This process introduces anisotropic residual stresses that can affect a part's performance. Our study uses an X-ray diffractometer (Proto XRD, Michigan, USA) equipped with a sin2ψ feature, to precisely measure stress and stress anisotropy. We analyze how different layer orientations in AM parts influence stress profiles. We are measuring residual stresses in various stainless-steel samples, each made using different AM settings, and comparing them to sheets made using roll stock. This approach elucidates differences in stress profile and how they spread throughout the part, especially how they change with different layer orientations and build parameters. Our findings highlight the importance of analyzing stress patterns as a function of layer orientation in manufactured parts. This knowledge guides us in using shot peening as a surface modification tool for both residual stress and surface profilometry.

HYDROGEN EMBRITTLEMENT IN SHOT-PEENED STEEL

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As hydrogen emerges as a key energy carrier for a sustainable future, concerns about hydrogen embrittlement in pipelines and structural components remain a critical challenge. Hydrogen embrittlement is the process by which hydrogen atoms permeate metal structures, causing them to become brittle and susceptible to cracking. Research has demonstrated that compressive stresses in metals can, in some cases, affect hydrogen diffusivity and suppress hydrogen ingress; however, the mechanism by which compressive stress influences hydrogen embrittlement in materials remains unclear. This study investigated the effect of hydrogen charging on 1070 steel treated with shot peening, a process that introduced biaxial compressive residual stress at the surface.

The objectives were: first, to examine how the residual stress state evolved when materials with pre-existing compressive stress interact with hydrogen atoms; second, to explore the mechanisms underlying hydrogen embrittlement under these conditions; and third, to determine whether inducing compressive stress via shot peening could serve as a viable strategy for preventing hydrogen embrittlement. The study used standard plain carbon steel Almen strips as test samples, with hydrogen introduced by electrolytic charging. For the permeability of H through shot-peened samples, the H-type cell was used. The sample was mounted into the sample holder and held between the two chambers in the H-type cell, serving with working electrode, counter electrode and reference electrode in each chamber. One chamber was filled with hydrogen charging solution and the other side filled with detection solution. The test terminated as the current densities reached a steady state, and the current densities were plotted as a function of time for both unpeened and shot -peened samples. To characterize the material response to hydrogen ingress, residual stress and X-ray peak breadth were measured using X-ray diffraction and the elastic modulus was determined through an ultrasound modulus test. Surface hardness was evaluated with a Vicker's microhardness tester, and TEM was used to examine dislocation structures. All these tests were conducted both before and after hydrogen charging of shot-peened samples to comprehensively assess the impact of induced compressive residual stress on the material properties. We observed that the elastic modulus exhibited only minor fluctuations during electrolytic hydrogen charging and subsequent release. A permanent reduction in compressive residual stress was noticed, despite the surface remaining hardened. The decrease in X-ray peak breadth suggested that the interaction between elastic stress and solute hydrogen facilitated local dislocation annihilation and structural reorganization. Notably, specimens with lower initial compressive residual stress, achieved through modified shot-peening parameters, did not exhibit a reduction in full-width at half maximum (FWHM). These findings highlighted the role of dislocation evolution in hydrogen-induced degradation, offering insights into the long-term reliability of hydrogen gas infrastructure materials.

NOVEL 3D OPTICAL METROLOGY FOR SHOT PEEN COVERAGE

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Traditional metrology techniques for evaluating shot peened surfaces often fall short in delivering comprehensive and efficient assessments. 2D stylus profilometry suffers from directional bias, struggles with complex geometries such as corners and edges, and provides limited surface coverage. Meanwhile, conventional 3D microscopy—though capable of high-resolution and areal imaging—typically lacks portability and demands lengthy acquisition times, making it impractical for shop floor integration. This paper introduces a cutting-edge, high-resolution 3D optical metrology system engineered for portability, speed, and precision in assessing shot peen coverage directly on the shop floor. The system offers robust measurement capabilities across diverse component geometries with minimal setup. We present a series of evaluation case studies focused on system accuracy, repeatability, and reproducibility under real-world conditions, demonstrating its potential as a transformative tool for process validation and quality assurance in shot peening applications.

Modeling of Industrial Shot Peening

REDUCED ORDER APPROACH FOR PEENING STRESS FIELD VARIABILITY

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A common goal in shot peening research is to connect operational parameters to resultant residual stress fields, providing a means to maximize the surface treatments effectiveness. In practice, experimental measurements of residual stresses are often averaged values over regions that are large in comparison to an impact dimple. The stochastic nature of impact locations leads to residual stress fields that are distributed in space accordingly.

Representative elementary volume finite element peening simulations confirm this observation. The goal of this report is to connect operational parameters to localized fluctuations in residual stress through probabilistic reasoning. In particular, the development of a Poisson process model to predict variability in residual stresses over measurement regions comprising multiple impacts, as well as a contact-mechanics based approach for predicting asymptotic variability in residual stress at sub-impact measurement length scales.

TEMPORAL ASSESSMENT OF MEDIA MASS FLUX UNIFORMITY WITH MULTI-AXIS LOAD CELL

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While peening aims to induce a uniform compressive stress field through an evenly distributed impact field, stochasticity is inherent to the process. This presentation focuses on temporal fluctuations in particle deposition rate arising from:

1) Low frequency cyclic motion of the component with respect to the peening nozzle.
2) High frequency fluctuations in media flow.

To investigate these effects, a laboratory-scale peening test stand was instrumented with a multi-axis load cell to measure body forces imparted onto a component throughout a peening cycle. Treatment uniformity is evaluated in the time domain, through the lens of a non-homogeneous Poisson process, by leveraging a Fourier transform of the force response to distinguish the relative contributions of high-frequency and low-frequency phenomena to surface treatment uniformity.