Newsletter 2015 No.3

IMAST

Institute for Manufacturing and Sustainment Technologies

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DIRECTOR'S CORNER

This edition of the IMAST newsletter is dedicated to cutting-edge technology, specifically Additive Manufacturing. The mission of IMAST, in support of the ONR Manufacturing Technology program, includes an ongoing imperative to find new technologies that have promise for improved efficiency in manufacturing and sustainment. This includes public shipyard and depot applications, as well as private industry. Additive Manufacturing (AM) has been getting a lot of press lately so I didn't want our readers to misunderstand the silence as meaning zero involvement by either ARL or the Navy ManTech program in general. From my viewpoint, there's a lot going on across DoD and industry. Regarding ARL's CIMP-3D lab, the support we're providing to the Navy through IMAST projects,

Timothy D. Bair

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STEM-3D... Educating the Educators

As student interest in science, technology, engineering and mathematics (STEM) declines, the Office of Naval Research has put forth an outreach effort to reverse that trend.

Jared Blecher, former ARL Penn State graduate student, discusses characteristics of additive manufacturing equipment with "Materials Camp for Teachers for Additive Manufacturing"® participants. (ARL Released photo)

Always a leader in leveraging technology and developing science-based solutions that address the numerous challenges facing the U.S. Navy-Marine Corps team, the Office of Naval Research (ONR) realizes that to continue maintaining its leading-edge advantage in naval science and technology, a pool of bright, motivated and creative engineers and technologists need to be available to fill the personnel void of retiring R&D personnel. To that end ONR has teamed up with educational and professional engineering organizations to initiate an outreach effort that will spur more interest in STEM disciplines and possibly stimulate career interest within the Department of the Navy. This effort is currently being accomplished through the introduction of exciting and motivating interactive science programs within classroom and learning center forums. This approach emphasizes K-12 engagements and collaborations.

While education is not the primary focus of the Navy ManTech program, it [education] cannot be dismissed relative to the pathway it provides towards the implementation process. This would particularly include (for example) the repair technology effort we are involved with throughout our work with depots and naval shipyards. Educating the work force that adopts new processes, as well as associated material applications, is a necessary requirement.

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DIRECTOR'S CORNER

as well as ARL's collaboration with "America Makes" translates into cutting-edge research aimed at process definition, characterization, qualification and, at the more practical end, parts put back on the ready line.

ARL Penn State's Laser Processing Division, in collaboration with Penn State University, are the hosts to the DARPA-designated DoD Manufacturing Demonstration Facility for AM. They are busy and getting busier every day. One of our recent new start projects for the Repair Technology program involves developing an AM repair for a NAVAIR turbine engine component that could be grounding jets in the near future. This "resurrection" repair, takes a part that has no current-approved repair process, out of the scrap bin and puts it back on the supply shelves, ready for installation. We love projects like this. Savings are big and the impact to Navy readiness is even bigger! We'll be showcasing this project in future editions after the final implementation is assured.

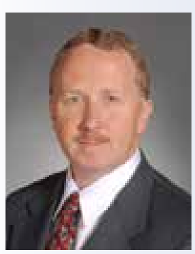
This newsletter's articles are provided for your education. I am confident the feature article will help you better understand AM in general, as well as start you thinking about innovative applications in your corner of the manufacturing world. The cover article of this addition talks to a service we provide as a part of being good citizens who want to pave the way for our future educational leaders. Helping the next generation see the value of a technical education is both rewarding and self-supporting (ARL relies on the education industry for its "most precious resource"—just like you do!). I fully expect to be schooled by some middle schooler on the AM process and advantages at some point in the near future. At least I hope that happens!

By the way, don't forget to visit us at DMC in Phoenix. We'll be at booth #829. This year, IMAST has been selected to present our ceramic thermal spray coating project effort in support of submerged materials and mechanical systems, as well as our Cold Spray applications project in the ship's maintenance world. We were also just notified that the Navy Standard Pressure Actuated Door was nominated for the DMC Achievement Award!

Please enjoy this overview and let us know if you have questions we can address. As a Navy ManTech Center of Excellence, IMAST strives to show value to its sponsor and the industries that we work with to meet our manufacturing and sustainment goals. As always, happy to serve—and thanks for reading!

Tim Bair

PROFILE



Thomas Donnellan is the Associate Director for Materials and Manufacturing at Penn State's Applied Research Laboratory. Prior to joining ARL, Dr. Donnellan served as Chief Scientist for materials at the Federal Bureau of Investigation. Prior to the FBI, Dr. Donnellan served as manager of structural sciences for Northrop Grumman Corporation. Previous to Northrup Grumman, Dr. Donnellan was the composites group manager for the Naval Air Development Center (NADC) at Warminster, PA.

Dr. Donnellan received his bachelor of science degree in materials engineering from Drexel University. He received his master's degree in polymerics from the Massachusetts Institute of Technology, where he also earned a science doctorate in materials science.

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MATERIALS PROCESSING TECHNOLOGIES · MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES · LASER PROCESSING TECHNOLOGIES · COMPLEX SYSTEMS MONITORING TECHNOLOGIES · COMPOSITES MATERIALS TECHNOLOGIES · NAVY/MARINE CORPS REPAIR TECHNOLOGIES · MANUFACTURING SYSTEMS TECHNOLOGIES

Focus on Laser Processing Technologies

Additive Manufacturing for Navy Applications

by Thomas Donnellan, Sc.D.; Richard Martukanitz, Ph.D.; Edward Reutzel, Ph.D.; and Todd Palmer Ph.D.

Unmanned Aerial Vehicle (UAV) exhaust components produced through additive manufacturing process. (ARL Released photo)

Currently, there is a great deal of interest in additive manufacturing (AM) technologies within a variety of industrial sectors driven by AM's potential to enable design innovation and to reduce component and system lead time and cost. Polymer-based AM processes and systems have been commercialized and have been used to produce non-structural components for DoD and industrial applications. More recently, metal-based AM processes and components have been developed, and in limited cases, implemented. For instance, GE is developing metal-based AM for engine components. For the U.S. Navy, AM has promise for repair and/or replacement of existing parts, for limited field production of needed replacements parts (or tools), and for innovative new designs for new systems. The Navy has a need to understand the real state of AM technology – and to develop an investment strategy which provides the greatest return for the Service.

As a Department of Navy (DoN) University Affiliated Research Center (UARC), the Applied Research Laboratory (ARL) at Penn State is well positioned to support an assessment of the benefits/risks of AM for the Navy, and support initial implementation efforts. Penn State has world-class Additive Manufacturing capabilities, concentrated in our Center for Innovative Materials Processing through Direct Digital Deposition, or CIMP-3D, which includes material design, powder characterization, additive manufacturing process, monitoring and control, component design, in situ and non-destructive inspection/qualification techniques, and component test capability. Based on this broad range of capabilities, we have active research and technology demonstration programs supporting the Department of Defense (DoD) and industrial applications. The Center primarily uses laser-based processes which can be used with either powder or wire-based materials and unparalleled materials characterization capability. Through the Defense Advanced Research Projects Agency (DARPA) Open Manufacturing Program, CIMP-3D has been designated an AM Manufacturing Demonstration Facility for the DoD. In addition, through the Office of Naval Research's Navy Manufacturing Technology (ManTech) Program, the lab has worked with key stakeholders within the Naval Enterprise to support the development and implementation of advanced manufacturing technologies throughout the fleet. This work has provided us with perspective and experience in successfully introducing new technologies into the fleet.

ADDITIVE MANUFACTURING: BACKGROUND

The initial development of AM was for polymer-based systems which provided a capability for production of customized low volume components for prototyping, and for some industrial applications. Examples of components which have been produced include brackets, attachments, vents, etc.. These components require limited structural performance. Polymer selection for an application is often made based on thermal stability and/or other characteristics such as smoke and toxicity of the materials released during a fire.

More recently, interest in metal-based AM for structural components has grown significantly. ARL Penn State was a key participant in early Defense Advanced Research Projects Agency (DARPA) work on metals AM, which was then called laser free forming and led to development of structural applications in the late 1990's. Aeromet Corporation, which commercialized the technology, built structures which are still flying on some DoD aircraft. In addition, the work provided a basis for the further R&D performed in metals-based AM over the last decade.

Research Engineer Corey Dickman preparing build on EOS M280 powder bed AM system (ARL Released photo).

Commercial AM systems can now build components with classes of alloys used in many naval applications, such as stainless steels, titanium alloys, nickel-based alloys, and refractory metals. Components made with these materials (using conventional cast and wrought processing routes) are often expensive due to the high cost of the metal as well as difficulties involved in machining these metals, not to mention the challenges in joining and assembly. AM offers the potential to circumvent some of these materials and process challenges through precise deposition of materials in production of net or near-net shape components.

Based on the promise of the technology, AM for structural applications is being pursued. Northrop Grumman has produced an AM warm air mixer for UCAS. AM is being used to repair compressor blades for commercial engine applications by BAE and other organizations. Lockheed Martin is pursuing AM for an F-35 Lightning AM flaperon spar which they project will save $100M over the 30 year life of the program. The most significant activity in AM is the GE Leap engine fuel nozzle. The AM nozzle is a single component which replaces a 20-part assembly and is reported to provide a 5-fold improvement in durability and be 25% lighter than the component it replaces. GE has developed the technology base necessary to support the use of this AM component in this critical engine application. In addition, GE is moving towards production fabrication of edge structures for fan blades in 2016, and a range of other components. The company has numerous AM machines with an envisioned production of 100,000 AM components by the end of the decade. GE is learning lessons of value for the Navy on the production of components (1000's/yr.) versus laboratory prototypes – which is the current state of most AM applications.

ADDITIVE MANUFACTURING: CURRENT STATE

Polymer-based AM has been used for non-structural applications on DoD and commercial platforms. One recent significant success in application of polymer-based AM to address specific Navy needs highlights the potential for the fleet. The Naval Air Systems Command (NAVAIR), working in collaboration with the Defense Logistics Agency (DLA), has demonstrated that AM can be used to produce non-flight critical replacement components which were limiting the flight availability of some naval aircraft. Aircraft with these AM components have been restored to full operational service. In the NAVAIR/DLA collaboration, important, practical questions regarding the contractually appropriate application of AM for repair parts have been surfaced. Questions such as DoN (or OEM) ownership of component design and performance data, DoN's ability to transfer data to non-DoN organizations, and Original Equipment Manufacturers (OEMs) approval/concurrence of replacement parts for platform application will need to be addressed for widespread use of AM to reduce Operations and Support (O&S) costs and improve availability. Component spare deployment strategies are a longstanding issue for the Navy and Marine Corps, and this NAVAIR program suggests that AM has the potential to positively impact the sparing plan for both non-structural and structural parts for naval systems.

As noted, metal-based applications are still emerging. Depending on the metal alloy, properties of as-processed AM materials are somewhere between those of cast and wrought material for the alloy. It has been found that secondary processing, like heat treatment, hot isotactic pressing, and finish machining, substantially improve important performance characteristics of AM materials. In identifying implementation opportunities, cast components are a good target of opportunity for metal-based AM. Cast metal properties are typically lower than forged products, and there is often a casting factor applied to the design, making it larger and heavier than comparable wrought designs. The implementation of AM processes for these components can provide improved performance and design margin over cast processes. The availability of cast components is also limited by the lack of domestic casting capacity, creating a production process choke point to which the implementation of more flexible AM processes can provide relief. AM performance compared to wrought products is often not favorable and may require design changes that take advantage of unique component architectures, such as truss structures, to enable the application. Use of AM for repair parts, such as doublers, is an important opportunity for AM since organic depots often generate (and own) the design. Additionally, such components are often readily accessible for subsequent in-service inspections. Another near term application for AM that is of interest to the Navy is in fabrication tooling, because of the speed with which new tools can be developed for use in

Notional AM part emphasizing ability to fashion unique advanced heat exchanger components with features on the scale of 100 microns. (ARL Released photo) a depot. Longer term, AM also offers the promise of functionally graded structures for the same cost as monolithic material-based structures. In the future, it may be possible to develop new designs which take advantage of AM capabilities, such as functionality manufactured into the component. Examples include lightweight truss structures, porous structures for hypersonic vehicle applications, or wear and corrosion resistant faces for sealing surfaces.

There are ongoing technology development and roadmapping activities occurring at the SYSCOM's and at OPNAV (as well as in America Makes and the other Services). Department of the Navy coordination is occurring via Navy Additive Manufacturing Technology Interchange (NAMTI) – a group which has representation from all of the relevant Navy organizations. R&D in AM is active and wide implementation of AM in the Navy is dependent on this work.

Critical R&D in progress includes:
- In-situ sensing & control technology/ quality control
- Large scale AM process development
- Process/microstructure/property modeling & simulation
- Process/microstructure/property characterization
- Supply chain modeling & simulation
- Open Architecture AM process system development
- Alloy and polymer composite development and characterization for AM
- Multi-material AM technology (e.g., transducers, electronic assemblies, munitions, etc.)

In addition to these activities, critical issues remain which will impact broad implementation of the technology in the Navy:
- Current generation of equipment: lacks open system architecture (which limits the ability to relate process parameters to part quality and performance)
- Current process technology also has machine/machine variability issues and doesn't have the level of system diagnostics and in-situ process monitoring and control needed for robust processes
- Durability of AM systems (process equipment, materials) in Navy environments – depots, forward deployed
- Prevalence of foreign-owned process systems
- Cyber security

This last topic, cyber security, is critical to the successful use of industrial AM. Cyber security is an issue for AM but one which is not much different from other processes in a digital environment which inherently have information moving among distributed design and manufacturing nodes. Information assurance will be essential for the digital thread. AM is particularly sensitive to cyber-attack because the "digital information packet" (which goes with the part) contains not only design information, but also detailed manufacturing process information, i.e., process machine settings. Additionally, there are more entry points for cyber-attacks. Current plans for cyber security are to apply best practices from other related industries (e.g., software development, secure data exchanges). For example, one approach is to generate a unique file signature at design completion, generate the signature again at arrival at the machine, and compare signatures to identify files that have been manipulated in transit. Cyber for AM is being discussed actively in the community (e.g., NIST-sponsored Cyber for AM Workshop/3 February 2015).

ADDITIVE MANUFACTURING: SUGGESTED NAVY STRATEGY

Like the introduction of any new structural material (e.g., composites), there should be a conservative, safety-conscious approach applied to implementation of AM for structural applications in the fleet, incorporating a purposeful graduation from non-structural to tertiary, secondary, and primary structural applications. We would suggest that a mid-term, 5-year horizon for broad application at tertiary/secondary level within the fleet (with a longer time horizon for primary structures) would be possible. Of course, this timeline is scalable based on the resources applied by the Navy and other resources within the community. Also important to consider is that AM equipment and process technologies are still rapidly evolving. Since the Navy is capital constrained there will not be funding to repeatedly update AM capabilities in the fleet. Since AM equipment can be expensive ($10'sK – $1M), the Navy must pick the right time for capital investment in the capability.

VAdm David Dunaway USN (Commander, NAVAIR Systems Command) examines AM build in concert with recent ARL Penn State capabilities assessment visit to determine AM applications at NAVAIR Fleet Readiness Centers (ARL Released photo)

For structural applications, AM systems should be deployed at an appropriate subset of the Warfare Centers and organic depots to help define and mature the technologies. Also, as the technology matures, the Navy must develop an appropriate workforce for AM design/process/characterization/inspection/ logistics.

In addition to support R&D that address critical issues in AM, the Navy's most significant contributions to AM are defining the infrastructure required for implementation: performance data development for components of interest; development of a certification protocol for these components; the use of the protocol to implement AM components on DoN applications; development of secure data exchange protocols; and the development of inspection/acceptance criteria.

FEATURE ARTICLE

Topological advanced design methodology specimen produced as part of a senior student project demonstrating expanded design space enabled by additive manufacturing. (ARL Released photo)

Maintenance and sustainment should be an initial focus for AM in the Navy. This includes both AM for repair of existing components and also remanufacture of existing components. O&S cost and lead time reduction using AM is the goal. The Navy needs to drive technology development and implementation for maintenance and repair because OEM's have no incentive to reduce the Navy's O&S costs. Since the Navy must lead the maintenance application of AM, near-term demonstration of an AM distributed network within the maintenance community should be performed in a controlled environment, within the Naval Enterprise, to understand the benefits/risks of the approach.

Subsequently, the Navy should focus on new designs and future systems and platforms which will build on much of the work performed above. Additional R&D focus in the area of new materials and new design tools will support development of improved performance and lower cost components. In addition, new machine designs which enable larger parts, faster throughput, and better part resolution will increase the range of DoN systems, which can benefit from AM's advantages. Finally, the Navy should develop the certification protocol to be used for the innovative designs and materials emerging from these activities.

Acknowledgment

The authors would like to express their appreciation for support of ARL Penn State's AM effort by the Institute for Manufacturing and Sustainment Technologies (IMAST), a U.S. Navy Center of Excellence under contract by the U.S. Navy Manufacturing Technology (ManTech) Program, Office of Naval Research. Any opinions, findings, conclusions and recommendations expressed in this article are those of the authors and do not necessarily reflect those of the United States Navy.

COVER STORY

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Within its goal of increasing the availability of future engineers and technologist, the U.S. Navy (through ONR) is targeting future engineers and technologist in its constant effort to keep our naval fleet relevant amid the reality of high operational tempo environments associated with challenging global commitments. With respect to creating programs that encourage interest in STEM disciplines, the question arises: "Who is going to teach the teachers?" In response to the teacher-end of the spectrum, the materials and manufacturing effort (through Penn State's Applied Research Laboratory) recently took the initiative to step forth and assist in developing the course. The Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D) hosted an ASM (American Society for Metals) Materials Education Foundation event titled: "Materials Camp for Teachers for Additive Manufacturing"®. The Materials Camp for Teachers venue has a proven record of strengthening curriculums in STEM disciplines, especially at the secondary school level.

Members of the 2015 ASM Materials Education Camp for Teachers join together for a group photo in Penn State's CIMP-3D facility. (ARL Released photo)

Through the course of a one-week teacher's camp (sponsored by CIMP-3D) participants learned the basics of materials science and technology—as taught at the high school level in this particular case. The opportunity to work hands-on with metals, ceramics, polymers and composites provided educators a special appreciation for materials supporting modern life. Teachers learned basic information and techniques designed to empower and infuse more creative concepts into existing science courses, thereby stimulating career interest (therefore) – leading towards increasing a larger pool of innovative engineers—some of whom the Department of the Navy hopes to attract one day into joining its own team of Department of the Navy engineers and technologist.

For more information about the ASM Materials Education Foundation, Contact Stephen Copley, Ph.D. at <smc21@arl.psu.edu> or Ted Reutzel, Ph.D. at <ewr1@arl.psu.edu>.

Dr. Tim Eden discusses Cold Spray technology with technologist at CAST meeting. (ARL Released photo)

Top photo- JDMTP members are briefed on Vertical Lift Center's Ground Resonance Demonstrator by professor Ed Smith. Below-members of the JDMTP pause for a photo during a tour of Penn State's famous Berkey Creamery (ARL Released photo)

Research Associate Ken Meinert (right) discusses specimen and capabilities of a directed energy deposition system at ARL's CIMP-3D facility with Captain Kalowsky. (ARL Released photo)

IMAST Participates in Cold Spray Action Team Meeting

Dr. Tim Eden, Director of ARL Penn State's Materials Processing Department recently participated in a Cold Spray Action Team (CAST) meeting at the Worcester Polytechnic Institute in Worcester, Massachusetts. Dr. Eden has incorporated several successful Navy ManTech projects using the Cold Spray Process. Practical uses of the Cold Spray application growth, as distinct from thermal spray, continue to evolve as expansion into the aerospace and DoD market increases. ARL Penn State remains committed to maintaining its leading edge position with respect to the technology and application by participating in all such events. MIL Spec (MIL-STD-3021 DOD Manufacturing Process Standard, Materials Deposition, and Cold Spray) continues to be adopted throughout the world, with a growing number of aerospace-qualified repair procedures growing.

Cold Spray technology will move into the marketplace much more quickly and smoothly as users, spray shops, equipment, and powder suppliers work together to share information, develop the engineering data, and match the technology to the best applications. As noted in previous IMAST newsletters, Cold Spray is a material-deposition process where metal or metal-ceramic mixtures of powders are used to form a coating or freestanding structure. The CAST meeting facilitates collaborations between many companies, government and academia. It has been estimated that program funding over $14M has been allocated toward the development of cold spray technology from 2011. Opportunities will continue for further Cold Spray research and development activities. For more information about ARL Penn State's Cold Spray activities contact Dr. Eden at (814) 865-5886 or email at <tje1@arl.psu.edu>.

IMAST Hosts Annual JDMTP Visit

Members of the Joint Defense Manufacturing Panel recently traveled to Happy Valley as part of an annual review of Navy ManTech projects underway within ARL Penn State's IMAST program. In addition to ensuring that the overall DoD ManTech program avoids duplication of effort, the panel also works to identify projects and/or technologies that the joint community could benefit from as well. In additional to project briefings, IMAST scheduled tours for the panel of Penn State numerous laboratories and advanced technologies to support JDMTP's mission to find new and innovative solutions for the DoD. This year's JDMTP members toured Penn State's Vertical Lift Research Center of Excellence, as well as the renowned Berkey Creamery, where leading-edge manufacturing takes place on an impressive scale.

Commander, PHNSY & IMF Visits IMAST

Captain James Kalowsky USN, Commander of the Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility recently had an opportunity to visit IMAST for an impromptu briefing and tour of ARL Penn State facilities. The shipyard and intermediate maintenance facility is responsible and accountable for the material readiness of ships and submarines home-ported at Naval Base Pearl Harbor. The command responds, as needed, to all points within the Navy's global reach. Captain Kalowsky commands a workforce of approximately 500 U.S. Navy personnel, in addition to 4800 tradespeople, civil servants, and support staff.

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"I do not want to be in a position of technological parity or inferiority with anyone in the world."
—Frank Kendall, Under Secretary of Defense for Acquisition, Technology and Logistics

CALENDAR of EVENTS

2015

22–24 Sep	Modern Day Marine Expo	** Quantico, VA
12–14 Oct	AUSA Expo	Washington, D.C.
3 Nov	NCMS Technology Showcase	Fairfax, VA
30 Nov–3 Dec	Defense Manufacturing Conference 2015	** Phoenix, AZ
12–13 Dec	ASNE Combat Systems Symposium	Arlington, VA

2016

12–14 Jan	Surface Navy Association Symposium	** Crystal City, VA
1–2 Mar	ShipTech	Charleston, SC
21-24 Mar	Airworthiness & Sustainment Conference	Grapevine, TX
17-19 May	American Helicopter Society Forum 72	West Palm Beach, FL
27-29 Sep	Modern Day Marine	** Quantico, VA

** Visit IMAST booth