Standardization of Tech Data Packages for Additive Manufacturing

Executive summary

This project will develop a standardized approach for producing tech data packages for metal AM components. The team assembled has expertise in developing 1) high quality powder metals 2) benchmark property data 3) ICME tools that predict properties and microstructures 4) ICME tools that predict thermal behavior during AM processing including distortion and dimensional accuracy 5) experimental tools that enable the measurement of key AM metrics including dimensional tolerances 6) novel DOE for streamlining qualification of beads for AM builds and 7) educational and workforce programs. The scope of the project is to use a standard geometry for a well-documented material (i.e. 316L, Inconel 718) to baseline our ICME/experimental approach and methodology. Using the lessons learned we will look at a unique geometry for a Titanium alloy component specified by our industrial partner that is looking to create it in a production environment at half its current time while also ensuring “as-designed” properties. While many of the sub-systems have been developed by the team, it has not been integrated into a streamlined package that can be easily utilized by industry.

A1

The technical challenge is creating a standard physics based methodology for understanding the relationship between process-property-structure (PPS) for metal AM tech data packages (TDP). This TDP will define the energy density requirements for creating a fully dense, functional metal component with associated material properties and dimensional tolerances. The TDP will also explain what key metrics should be monitored and controlled (i.e. net heat input) during production to maximize process efficiency while reducing the need for post processing and or final inspection.

Our knowledge of the relationship between PPS for metal AM is based on empirical data, so we lack a full understanding of what the real energy requirements are for delivering the necessary material properties for a given structure within the processing parameters available on any given system. Without a standard physics based methodology for understanding PPS we can’t fully exploit AM’s potential. This project combines ICME with experimental tools and databases to provide a uniform independent methodology that will speed up the development process of new designs and materials.

A2

Since a physics based approach is utilized to define the process-property-structure relationship, it will be possible to know what key metrics must be considered when developing the standard methodology. Additionally since we will measure and monitor these metrics experimentally it will give us further confidence that our process choices will give the necessary results. The deliverable from this project will incorporate software tools and process monitoring guidelines that will ensure a streamlined product/material development methodology for TDP regardless of the AM system.

Development of a standard methodology for the AM TDP by looking at energy requirements at a fundamental level is required. By providing physics based guidelines and processing windows end users will have confidence when printing. The foundation of this process-property structure relationship which is central to a well based AM tech data package will be given in the form of a spreadsheet that can be built on and expanded as new developments are made. This currently does not exist in the field and must be introduced. It will include at least one example for a standard geometry.

A3

Ed Herderick from GE stated that “it can easily take over 5 years to qualify for industrial use one new material manufactured using a specific process”. Developing rapid qualification strategies that are based on comprehensive tech data packages is the only way to overcome this barrier when creating new materials. This project lays the foundation of such a tech data package that can reduce the development time to less than 1 year. With that shift in development, innovation in America will grow and it will strengthen our supply chain and pave the way for new industries.

Despite many publications on the progress AM has made with materials like Ti-6-4, it’s very difficult to directly compare the results given in the literature because very little information is available on processing parameters, part geometries, etc…Without this information it will be difficult to make the necessary connections between, processing, properties and microstructure. That is why what is proposed here is so important, a foundation must be given and the proper models and experimental data must be defined and given so that others can begin to make direct comparisons.

A4

As a global leader in ICME approach, QuesTek designs and develops new high performance alloys. They have currently developed an AM specific alloy in Ti. Therefore, we are confident of the alloys that will be made due to the involvement and help from Cristal Metals Inc., a supplier of premium Ti powder. NIU, NU and QCML have been working on a joint NIST MSAM project where they have developed a series of databases, in situ process monitoring and ICME tools that are fairly advanced and can be further developed under this program. Our SMEs have experience in AM component development and will test our approach.

QuesTek has successful done alloy design with projects like: DARPA “Open Manufacturing” Nickel 718+ superalloy for DMLS, Honeywell Manufacturing Affordability Initiative (MAI) program for ICME development of Ti and Ni alloys for aerospace components. NU has publications on work done through the NIST MSAM project linking process, structure, property, and performance for metal-based additive manufacturing using computational approaches with experimental support. NIU has several articles coming out that detail experimental tools developed for process monitoring.

A5

This market understands the value in this IP. Currently, there is one approach being used known as MiCloud.AM it incorporates GE aviation and a few other large players in this space. This mainly appears to be an ICME approach, the difference between this and our approach is that we define the required experimental tools that will measure the energetics that will go into a database that can be searchable by various methods (tbd by ASM international). This space has a lot of growth potential but should not be limited to only for profit solutions especially if America Makes wants it to grow.

Without an open format methodology to develop an AM tech data package it will be very difficult to advance the industry. There is a lot of research going on in AM. However, as stated earlier there is no way to compare the results from the research since most of the information is either incomplete or missing. If America Makes funds this project it will be the first ever solution in which people can compare and share data. This is just a beginning structure that can be built upon or modified as more knowledge is gained for tech data packages. Most of that will come from end users like GPI prototype.

A6

ASM will lead the team to develop content that is critical in understanding the importance of the entire process-property-structure relationship with a series of modules. PDA will work on distortion prediction and dimensional measurement using optical methods for dimensional tolerance assessment. Our focus is hands on learning with instructor led labs that will first target university classes (i.e. NIU’s MEE 432) but will be modularized so it can later span from K-grey. The aim is to grow that understanding as we move throughout the educational experience to create tired skill sets.

The value of developing a pipeline at various levels is critical so that we cultivate the necessary talent for the market needs. At the early stages, it is important to provide the basics of AM. Later on with further development in CAD/CAM capabilities these modules can focus on some basic training and potential real world experience with small SMEs that require support in the areas of CAD/CAM. Later, at the university, it is possible to develop a further understanding and so the modules can reflect around the importance of research and providing support to industry in product development.

A7

There is MiCloud.AM, a paid service for specific ICME database information. Otherwise the main approach to TDP’s has been through collecting large amounts of empirical data. We aim to develop a comprehensive ICME, experimental TDP that comprises of, specific energy requirements, key process monitoring indicators, and the corresponding mechanical properties. There will be guidelines that can be followed to ensure proper development of whatever geometry is desired. Additional ICME tools to aid in process development and a web based interface enables further improvement of the TDP.

This approach is important because by creating a standard methodology for the TDP, based on basic physics principles ensures future material developments are possible. Combining the requisite ICME tools along with key process monitoring guidelines that can vary based on material and geometry makes the TDP more flexible. In addition, data collected through this approach will have high reliability and thus provide confidence to the market, with the expansion in confidence the boundaries can be pushed and it is possible to establish acceleration of product/material development by 5x.

A8

We are working with:

1. Questek wants to expand its capabilities by offering a comprehensive solution to its customers.
2. GPI prototype works in Ti so they are interested in speeding up their development process to attract more customers and service the DoD.
3. PDA has created web-based search tool capturing the best practice data for casting, they want to do the same for AM.
4. Orelikon METCO and Cristal Metals Inc. want to sell more powder so if a universal TDP exists more people may consider using AM.
5. GSO wants to enter the AM market with a low cost 3D contouring system

While we will have a functioning series of ICME and web based tools that can be combined with guidelines for process monitoring which improves reliability and repeatability, some further refinement for a seamless operation will be necessary. Having all the components in place, with a web based interface will have a strong impact in industry because it will reduce product/material development by an order of magnitude. In addition manufacturers will build with more repeatability and thus reduce the amount of post processing and inspection.

A9

Once the tech data package template is created having included all the necessary tools and guidelines that this team will have developed and/or built based upon previous experience, anyone should be able to add new materials and or subsystems to further enhance the package. Our intention is to highlight the necessary fields that must be addressed in order to have consistent and reliable data, build after build, regardless of the AM system used.

It will be possible to improve and update the TDP because we will have defined all the important needs for the comprehensive tech data package (i.e. ICME tools, process monitoring guidelines, etc...). As such people would only need some form of the experimental tools used to collect the data during builds as prescribed by the guidelines and some computational capacity to run the ICME tools. In addition the web based decision tool can be accessed and improved as more information is learned.

A10

This approach will create significant improvements because it will provide insight into AM systems and their energy efficiencies. In our NIST MSAM work, we have shown through our calorimetry data that it is possible to utilize the same processing parameters on similar systems. However, if they are not operated in the same manner while you might obtain same mechanical properties you may run at lower efficiency which means you will consume more energy than you need to. Therefore, operator and system variability should be considered. Currently no other tool like ours exists to do this.

This capability is important because as we ran the same processing parameters on similar systems we saw that one system operated at a 30% efficiency while the other at a 44.5% efficiency. That is almost a 15% difference on energy consumption. One can immediately realize that if you can run at a better efficiency in the long run you will save a lot of money through reduction of energy consumption. Often times simple changes on the system can help drastically improve process efficiency.

APPLICATIONS

1. Accelerated product development cycle – It will be possible to reduce the length of time required to qualify a new material for industrial use which is beneficial for the end user as parts created can result in significant cost savings and improved productivity/efficiency.

Parts of it are operational with some prototype testing, more work is required

1. AM powder and process specification development – It will be possible for end users to quickly select a powder and understand what the specific processing windows are required for a given material to obtain desired properties.

At this stage it is partly conceptual with some prototype testing work done

1. Uncertainty quantification and management – it will be possible for end users to have a firm understanding of what any potential issues may arise through the ICME component and thus make it possible to drastically reduce, down time, scrap rates or other areas that can negatively impact production.

At this stage this is mainly conceptual

B1

This project includes the development of several ICME packages that will be combined with a web based tool that when pooled together will enable the rapid development of metal AM components. In addition a guideline will be provided of what key processing windows should be monitored during builds based on data obtained through experimental measurements of key metrics as predicted by the ICME tools. Finally a module for instructor led labs will be developed that will have a general structure based on project based problem solving that can be utilized from K-grey with a focus on understanding design, material selection and key processing parameters that will provide consistent and repeatable builds.

B2

QuesTek will utilize its knowledge on DMLS of 718 to test property and microstructure prediction for DED of 718, Ti alloys follow. NU’s ICME tools that predict thermal behavior during AM processing including distortion and dimensional accuracy will be used for 718 and Ti. PDA and GSO will utilize residual stress and distortion prediction to validate the AM parts with optical metrology and compare native CAD models to help with upstream assembly. These tools will be combined to have thermal, microstructure and mechanical properties all tied together. NIU and QCML will utilize process monitoring tools to help define required energy for building components which will then be used to help refine the process parameter windows. Our material suppliers will give their input on qualifying materials and our SMEs will test out these systems and expand where possible.

B3

For the group when utilizing process monitoring tools the main challenges are ensuring having the appropriate scales and sensitivity when geometry shape and size change to make sure they are scalable. The transition from simple to more complex geometries will not be easy and as such a stepwise approach will be required so that limits can be detected early. With the ICME tools available to the group we are confident that we can test out the limitations and define the windows as needed to minimize measurement error.

B4

**NIU:** Accurate process monitoring tools with experience from NIST MSAM project, LENS system – **NU:** World class research facilities and strong ICME group for thermal modeling and mechanical properties –**QuesTek:** World leader in ICME processing and microstructure prediction – **GSO:** Leader in software controlled holographic interferometry – **PDA:** physics based process modeling for over 25 years including digital scanning, CAD and FEA; web-based search tools for design engineers to assist select the process and material for AM – **WIU-QCML:** AM Processing Capabilities (LENS and EOS systems) and Education/Training expertise – **ASM:** Take sample data sets and help establish schema and templates for best practices in data management – **Orelikon METCO:** Inconel alloy experience – **Cristal Metals Inc.:** Ti alloy experience – **GPI prototype:** Manufacturers of AM Ti components (at least 9 PBF systems)

B5

We anticipate an 18 month project with $900k required from AM and $975k as cost match

B6

The market entry strategy will be to offer AM members access to the tools developed for a specific project they may require a rapid turnaround. The offer could be complimentary for the first attempt followed with a reduced pricing and finally as it matures develop a costing structure based on needs. In addition the team works with many SMEs and OEMs that may not be AM members but would require this service so a webinar would be offered to those individuals and companies. The IP will be shared with the group and as stated before provided to AM makes members with the hopes that other may want to adopt and expand the framework that was developed. The idea is that if well-developed people will want to join AM just to have access to the TDP. By end of project we should be close to TRL/MRL 5 and so the opportunity to expand or seek additional funding will need to be made at the 6 month mark of the project.

B7
The team works very closely with professional societies, OEMs in military and transportation, DOD RDECOMs and labs as a subject matter expert (SME) for design and manufacturing of metal parts and provides contract manufacturing for low volume production and intends to expand the business into AM for metal parts leveraging all team members. The impact would be high due to the nature of requirements for DOD since they require rapid turnaround and qualification and certification of components without this approach those needs will not be met.

B8

We will work together with the following entities: (1) Quad Cities Manufacturing Innovation Hub (QCMIH), which is a network of regional businesses, along with universities and community colleges. (2) NIU EigerLab innovation hub and accelerator which holds courses for entrepreneurs who are interested in learning about AM technology. In addition, with the help of ASM and PDA we will develop new curriculum content that they can distribute and disseminate through large networks. The emphasis will be on design and manufacturing including process modeling and web-based tools, this has been done successfully by PDA in AM funded and YBI managed Sand Printing project working as course instructor and content developer.

1.1

We will address the maturation requirements for the process-property-structures by having a combination of experimental and ICME tools to carefully define processing parameters and feedstock material specification alternatives to the resulting microstructure and material properties; a framework and methodology integrating such tools.

1.2

This IP will create a large impact by reducing development time by 5X and creating efficiency improvement on process as we exemplified for one case by 15%

1.3

As described above, it will help reduce energy requirements which is critical to supply chains but will also increase the turnaround time making these supply chains more robust

1.4

As stated previously, the team will develop some ICME tools along with experimental database for Inconel and Ti alloys so that when a given geometry and or mechanical property is necessary these tools combined will reduce the time needed to reach those requirements.

1.5

It will be possible to measure success early on. That is why we chose Inconel to start since it is better developed and understood as a material for AM. Once we have proven that our approach can work, we will further explore the Ti alloy. We may not complete the Ti alloy work, but we will have made enough progress to show the path forward such as to be able to finish it in the future.

1.6

This is a revolutionary step forward in AM tech data packages because it will combine the energy measurements obtained experimentally to further aid the physics based ICME approach. With that the ICME tools will help define the processing windows for validation. The guidelines for which process monitoring is critical to ensure repeatable results will then allow for rapid Qualification and certification

1.7

IP is very clear in this case and we will work towards a common understanding of how things will be developed and who will retain what IP rights moving forward

2.1

Yes, the target market as mentioned can be from K to Grey. At this stage, more specifically the target audience consists of colleges, universities, community colleges and workforce training and development.

2.2

Yes, it is well understood by this team what the educational component requirements are, which relate to having an educated workforce that is competent in AM design and manufacturing. There is no directed system that comprehensively looks at all the aspects from design, to processing, to operational monitoring. We are teaming with ASM and PDA to use their expertise to ensure the content will be comprehensive and manageable for the different target groups.

2.3

Yes, specifically we will look at instructor lead hands on courses which will aim to improve on developing meaningful experiences that will expose students to the design and engineering process, building and manufacturing skills, and the communication of project results and design decisions to peers and stakeholders. This will also include creating experiences in which students learn the benefits and limitations of the technology, material, process, and cost constraints, how to exploit design freedoms, limitations of CAD/CAM/CAE tools, and AM process physics.

2.4

At the conclusion of this project, there will be a fully developed comprehensive curriculum for an instructor led training that will incorporate design, material selection, processing parameter requirements and modeling basics.

2.5

We are confident that what will be developed in this partnership will be of value to universities as well as corporations as it will enable them to train the future workforce that is required.

2.6

Yes, it will be possible to expand and further explore how to improve this educational experience

3.1

Orelikon Metco and PDA LLC have expressed interest in the IP

3.2

GPI prototype has expressed interest in the IP

3.3

Professional societies like AFS, SME, government organizations like NIST and DOD along with the teams OEM customer base can benefit by having a common AM TDP. We also see value in deploying the web-based search tool for AM to expose more markets to the capabilities of AM.

3.4

Competition could come from MiCloud.AM which has an ICME component to it and is a database of specific materials. It may be beneficial to reach out if phase I is approved to ensure we have the right member involved.

3.5

There is an entire movement on standardization of material properties and database. If we are successful with this TDP we can work with all the organizations and universities who are actively involved and build on what comes out of this program.

3.6

It would be the ICME tools that are improved for this program.