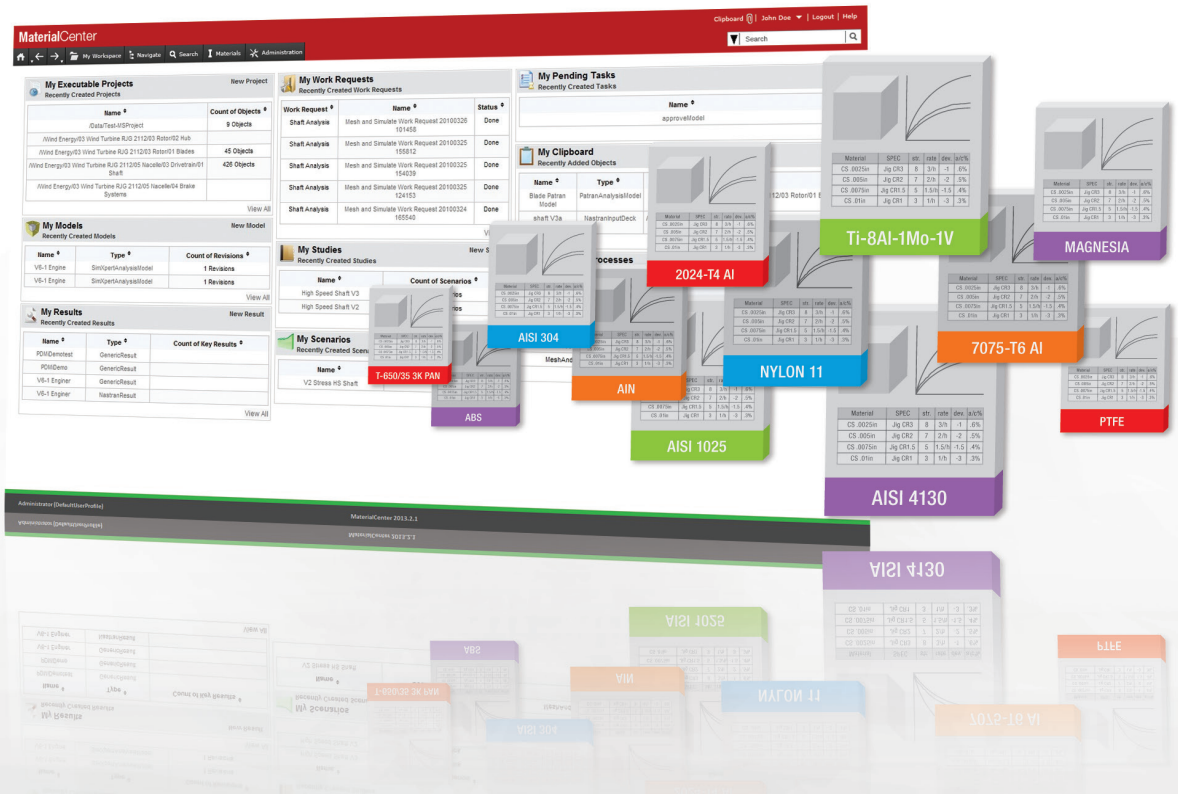
WHITEPAPER

Additive Manufacturing With Next Generation Material Lifecycle Management System



MSC Software

MSC Software Corporation, the worldwide leader in Engineering Lifecycle Management, would like to share some of our experiences and expertise in the application of Next Generation Material Lifecycle Management (MLM) system.

THIS WHITE PAPER introduces Additive Manufacturing (AM) techniques, widely known as 21st century manufacturing, and its challenges. These processes related to material, machine qualification, process characterization and application continue to be major consideration factors in producing quality parts/assemblies. MSC Software's advanced MLM system known as MaterialCenter manages the workflow of additive manufacturing from customer requirement to final delivery. It acts as a repository and maintains pedigree information of all machine/process/build parameters through all stages of product lifecycle management. The system develops predictive part behavior to quantify part performance (stiffness, strength and life) and allows the usage of all stored data to guide emerging R&D and future method development.

The paper is primarily intended for two type of readers:

ENGINEERING/MANUFACTURING MANAGERS who are involved in managing various phases of design to production in additive manufacturing.

DESIGN/CAE/PROTOTYPE TEST & BUILD ENGINEERS who are involved in the day to day product lifecycle activities (design/development/CAE/prototype build and test) and interested in improving the end quality of AM parts/assemblies via application of an advanced material lifecycle management system.

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1. EXECUTIVE SUMMARY

Traditional or conventional manufacturing methods have historically focused on the conversion of basic raw materials in various forms into finished product through subtractive processes. These techniques use well established design/fabrication methods, tools, equipment (e.g. foundry, lathe, CNC, etc), production activities and steps.



Figure 1: Traditional manufacturing

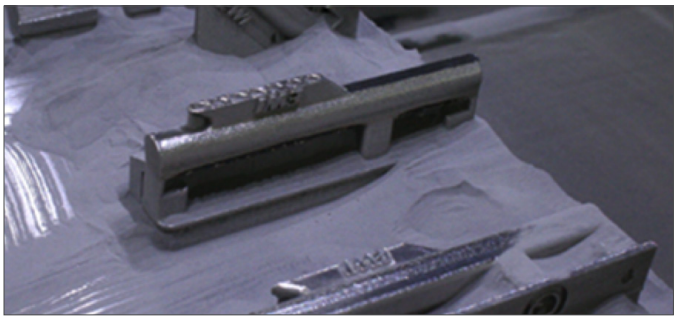


Figure 2: Additive manufacturing

Additive Manufacturing (AM) is a monumental shift from conventional manufacturing methods. Widely known as 3D printing, AM is modern manufacturing. Fig. 1. and Fig. 2. present both types of manufacturing processes.

The global AM market consists of 3D printers, materials and service providers. Applications are targeted towards rapid prototyping and rapid manufacturing. The entire market excluding materials is expected to reach $11.4B by the year 2020 at an annual growth rate of 21.0% from 2016 till 2020. Fig. 3 (a) and 3 (b) illustrate the global AM market and major industries.

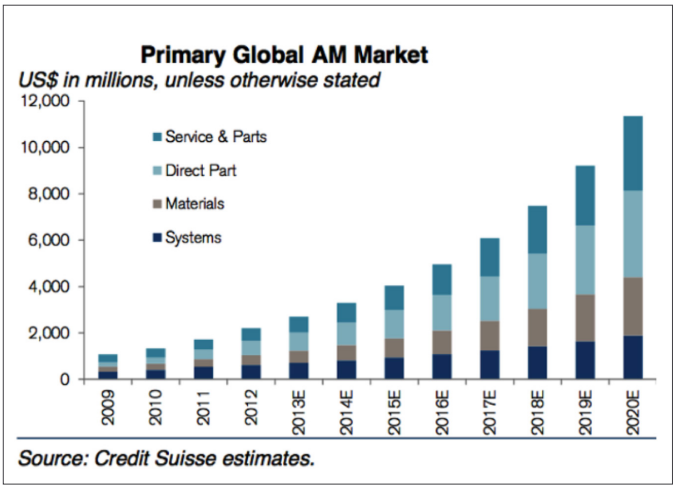


Figure 3 (a): Primary Global Additive Manufacturing Market

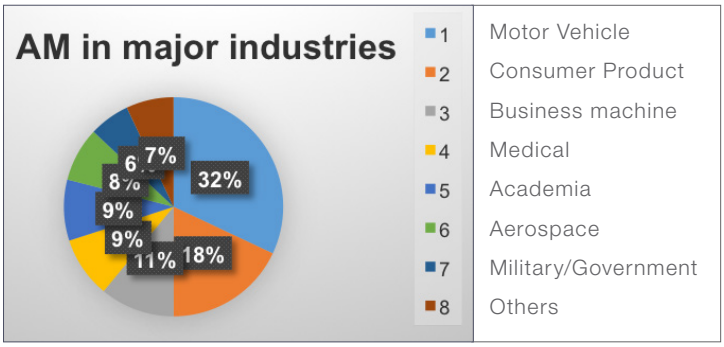


Figure 3 (b): Industries that use AM technology

Standards set by the ASTM International F42 committee play an important role in the adoption of AM technologies. The standards established by ASTM are geared towards materials, processes, technology, design, data formats and test methods. These have proved to be inadequate in the production of quality AM parts.

AM technology poses a number of challenges from Design to Production phases. Part manufacturers and leading AM researchers have identified the following as the some of the key indicators behind poor product design and after market performance of AM products.

1. Lack of governance in implementing Material Lifecycle Management in AM processes;
2. Inaccurate study of manufacturing variability that affects material properties;
3. Wide variation in machine/process control parameters that affect the quality of AM parts.

MSC Software's MaterialCenter (MC), the next generation Material Lifecycle Management System, has optimized the process of material data/process management and addresses "Left of Test" and "Right of Test" with relation to Additive Manufacturing lifecycle stages. This commercial off the shelf (COTS) solution, in use for over 20 years (former name mVISION), applies a combination of methodical principles, robust techniques and state of art statistical tools to improve the end quality of AM parts and assemblies.

2. ADDITIVE MANUFACTURING PROCESS

Parts manufacturers experimented and commercialized Rapid Prototyping (RP) techniques in 1980s and 1990s to a high level of perfection. Those techniques were used to fabricate scale model of a physical part or assembly using 3D Computer Aided Design. This eventually gave rise to Rapid Tooling (RT) - the production of tooling directly from a RP process.

Late 20th century advances in manufacturing created the demand for a new class of processes called "Additive Manufacturing." Kenneth Sabo, Concurrent Technologies Corporation, presented the benefits/challenges of AM processes at SHIPTECH 2016 Conference on March 3rd, 2016 at Charleston, South Carolina. Table 1 presents the summary of AM process benefits/challenges.

Common application of Additive Manufacturing may be found in the following products. Fig. 4 exhibits a sample part produced via Additive Manufacturing.

- Medical Implants;
- Mold/Die manufacturing;
- Weight Reduction through topology optimization;
- Brackets/Tools/Fixtures;
- Patterns;
- Custom fit assemblies;
- Small production runs.

Benefits	Challenges
1. Low Quantity Requirement	1. Qualify machine/process materials
2. No tooling, No Setup	2. Consistency across all machine/builds
3. Geometrically Complex Design	3. Cost effective logistics solution
4. Custom Fitted Parts	4. Innovate process control
5. Better Strength than Wrought / Cast	5. Lower ductility than Wrought/cast
6. Excellent for Prototypes	6. Must control in process distortion

Table 1: AM process benefits/challenges



Figure 4: Fuel Nozzle of GE Leap Engine

3. WORKFLOW FROM DESIGN TO PRODUCTION IN ADDITIVE MANUFACTURING

Additive Manufacturing is the process of producing a 3D object from Computer Aided Design. In an additive process, an object is created by laying down successive layers of material until the entire object is created. Steps 1 through 7 present the workflow as an object moves from design to production. Fig. 5 illustrates typical AM workflow.

Step 1: Computer Aided Design (CAD)

Additive Manufacturing workflow begin with CAD. Designers sketch, position, assign material, color and glossy/matte finish of a given AM part. The CAD model is examined for errors around holes, faces normal, and self-intersections and if required, and is reconstructed with higher accuracy.

Step 2: Generation of Stereo lithography (STL) file

The design, model translation and position of the 3D object in the tray are saved/stored as one STL file.

Step 3: Input into Catalyst software

Once completed, the STL format file is processed by a Catalyst software that converts the content into a series of thin layers (3D slices) and produces a G-code file containing build information tailored to a specific type of 3D printer.

Step 4: Print in Dimensional Printer

The G-code file is loaded into the 3D printer. The 3D client specific software instructs the printer to initiate the 3D printing process. It reads in the data, lays down or adds successive layers of liquid, powder, sheet metal and other in a layer upon layer fashion to fabricate a 3D object. Printer resolution describes the layer thickness and X-Y resolution in dots per inch (dpi) or micrometers (um). Typical layer thickness and X-Y resolution is around 250 DPI, although some machines can print as thin as 1600 DPI.

Step 5: Take Sample Out, Measure & Test

Production of a given 3D part may take a few hours depending on the type of machine and complexity of geometry. After the part is produced, it is measured, tensile tested and checked for surface roughness.

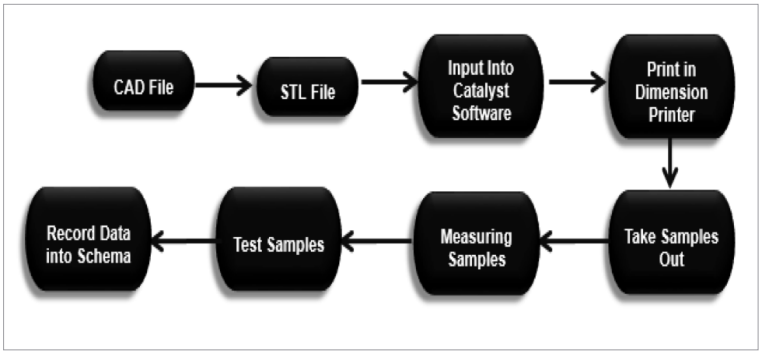
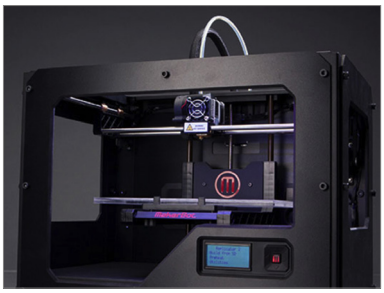


Figure 5: Workflow of standard additive manufacturing

There are a number of commercial 3D printer manufacturers. A typical AM 3D printer is shown in Fig. 6. A typical build tray and print head is presented in Fig. 7.



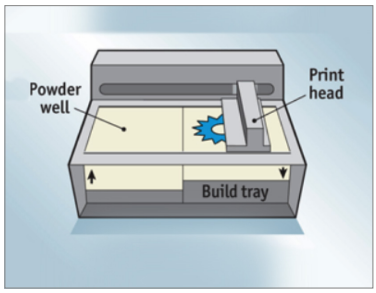


Figure 6: MakerBot replicator 2 AM Machine, Figure 7: Typical AM Build Tray & Printhead

4. COMPARISON OF ADDITIVE AND SUBTRACTIVE MANUFACTURING

Dr. Swee Mak, Director, Future Manufacturing Flagship, CSIRO, presented the following Fig. 8. on June 4th, 2014 Hunter Research Foundation meeting. He concluded that, “in comparison with traditional subtractive manufacturing method in which a block of finished material is machined down to make a product, additive manufacturing methods are fast, use less energy, and generate less waste material.”

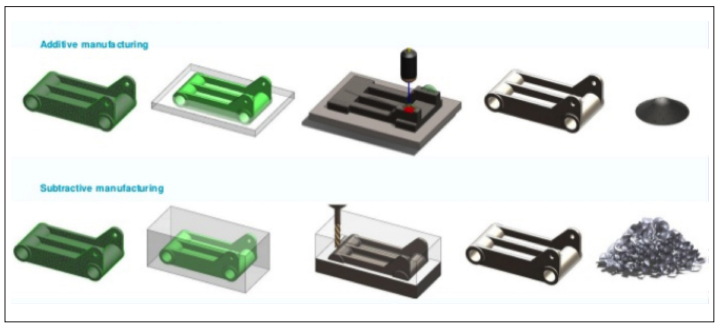


Figure 8: Comparison of Additive and Subtractive manufacturing

5. CONSIDERATION / MAJOR CHALLENGES IN AM

Additive manufacturing has made significant strides over the past 25 years. However, technical challenges related to materials, equipment, machine / process variation and application continue to be major consideration factors in producing quality parts.

Mr. Kenneth Sabo, Director, Concurrent Technologies Corporation (CTC), summarized CTC research and presented in the ShipTech 2016 Conference. Fig. 9. presents the challenges in AM design to production stages.

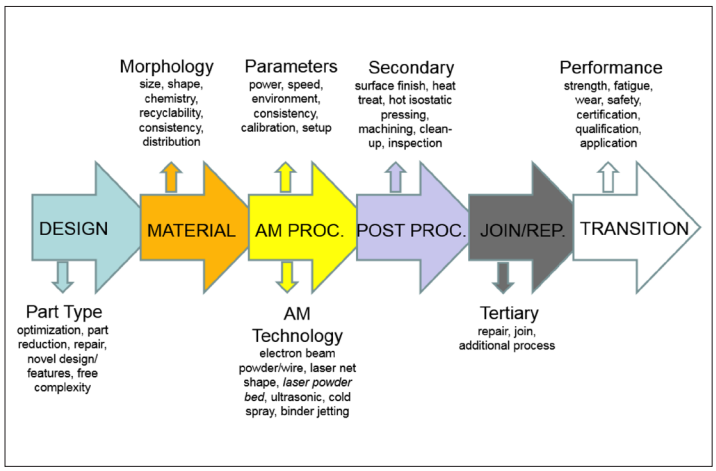


Figure 9: Challenges in AM design to production Stages

Design to Production includes challenges in material characterization, machine qualification and process varaition.

- Materials Characterization: Currently, AM parts producers do not have a central repository of materials property data. The industry cannot fully transition to offer complete manufacturing solutions unless/until material properties data for available materials are recorded/stored. AM material capabilities for part selection (e.g., material properties as a function of build orientation, tensile strength, yield strength, environmental considerations, fracture toughness) need to be researched/recorded and made available for all manufacturers. If the material properties of AM parts are not available, engineers/ designers will not consider AM as method of manufacturing
- Process Variation: Existing methods are inadequate to address the process repeatability and uniformity. Sometimes as high as 85% scrap rate is recorded for powders. Innovative methods need to be developed to improve early defect detection. Better process controls will lead to reduced machine downtime – currently a major issue for many machines and processes.
- Machine qualification: Machine to machine as well as part to part repeatability is noted to be high. Part placement consideration (part placement, location and build angles based on machine capabilities) needs to be fine-tuned. Material strength relative to build axis/orientation needs to be estimated via statistical analysis. A series of "what If" studies is required to understand the high level of variance.

Most of the mid/large sized US manufacturers deal with the above challenges on a day to day basis. Some of the concerns expressed by them are as follows:

1. Is additive manufacturing producing lightweight, cost-effective, quality products?
2. Does additive manufacturing make sense?
3. What should I recommend to logistics/suppliers?
4. What is the sensitivity matrix of key variables?
5. Why is the surface finish too rough or too fine?
6. Why is powder scrap rate so high?

6. APPLICATION OF NEXT GENERATION MLM SYSTEM IN ADDITIVE MANUFACTURING

Materials Lifecycle Management (MLM), a subset of Product Lifecycle Management (PLM), provides linkages between items and attributes about information items as well as the information items themselves of "Left of Test," Actual Test Cycle and "Right of Test." Thus, it directly addresses the issue of the traceability of data in complex environment. This is because the system stores the pedigree of the information creation process for each process step. The data, stored as an information structure, is interpretable both by people and by computers, defining the exact context of each item of information. Fig. 10 illustrates the lifecycle stages of MLM.

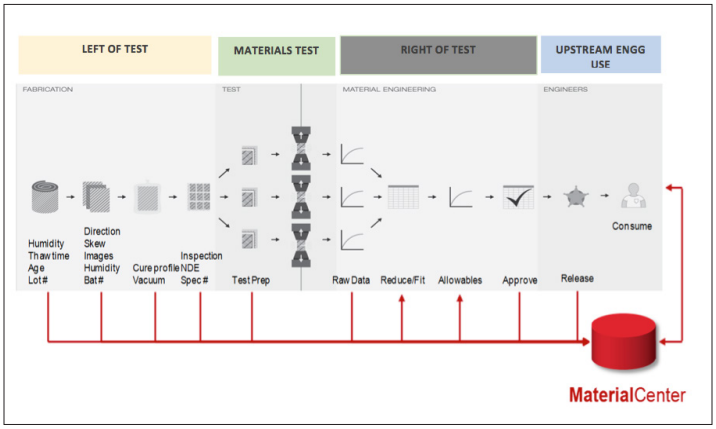


Figure 10: Materials Lifecycle Management

Traditional MLM systems cannot address the challenges posed by AM processes. Next generation MLM systems are architected/developed/ implemented specifically to solve AM issues from design to production stages.

Advanced MLM systems integrate Additive Manufacturing to Physical/ Virtual tests to CAE, PLM/PDM. Some of the capabilities are listed below.

1. Integration of full AM workflow and approval process;
2. Material traceability during various lifecycle stages;
3. AM Machine data/process management for physical/virtual – manufacturing and test;
4. Process engine that supports open interface to 3rd party softwares and databases;
5. PDM/CAD/CAE/EAM/MES agnostic system;
6. Import/Export from/to CAD and CAE Solvers;
7. Secured and controlled data exchange within/outside of corporate entities.

Fig. 11 displays the ecosystem and integration touchpoints of next generation MLM system.

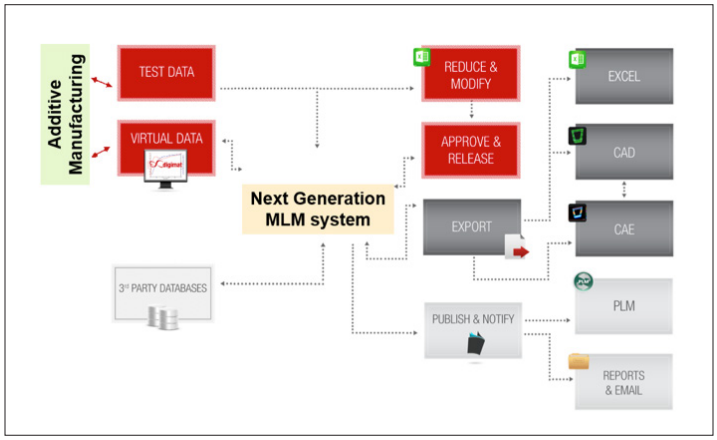


Figure 11: Ecosystem and Integration touchpoints of Next Generation MLM system

7. MANAGEMENT OF AM WORKFLOW IN MSC'S MATERIALCENTER

MSC Software's MaterialCenter (MC) is an enterprise-scalable next generation Material Lifecycle Management system. The intuitive web-based interface allows engineering organizations to virtualize material or part/machine/process/additive manufacturing behavior. The integration framework of MC enables accurate transmission of information to other stakeholders in a given organization.

The automatic capture of results for comparison, confidence and certification – all with complete traceability in MC – brings a new dimension to additive manufacturing. It provides a comprehensive workflow tool which enables the capture of information at every step of the manufacturing process from concept to final build. Samples of benefits of this advanced web based tool are as follows:

1. Workflow management from Customer to Engineering/Manufacturing;
2. Database of CAD/STL information;
3. Record of all environmental/manufacturing conditions;
4. Repository of all machine/process/build parameters;
5. Statistical analysis of samples, machine/process parameters to perform "what if" studies;
6. Pedigree information of material/machine/process/prototype build and test actions;
7. Develop predictive part behavior model to quantify part performance (stiffness, strength and life);
8. Generate machine qualification scheme and control library;
9. Reverse engineer material properties via integrated FEA solvers (MSC/Digimat);
10. Usage of all stored data to guide emerging R&D and future method development.

Standard AM workflow (from importing customer's requirement to managing all tasks in an automated mode and finally reporting back to customer) can be achieved via MaterialCenter. Industrial clients have reported a return of investment (ROI) in excess of 40% by utilizing MC in the management of AM processes.

Fig. 12 presents the management of AM workflow in MC environment.

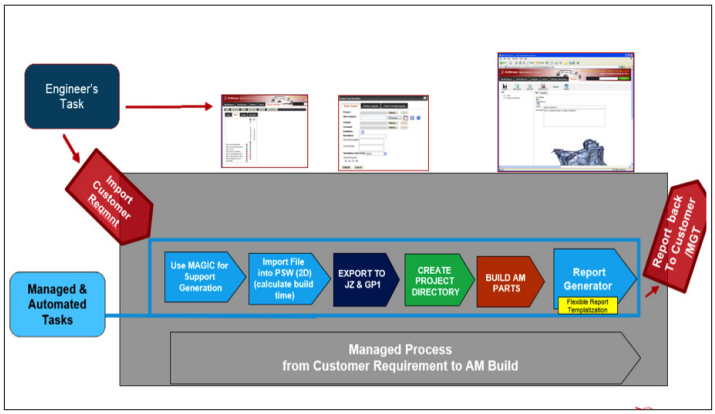


Figure 12: Management of Additive Manufacturing workflow in MC

MaterialCenter's Additive Manufacturing Schema is derived from years of research conducted at PennState University and the United States Army. It includes metallic/non metallic/plastic AM processes. The system can be used as a repository of manufacturing attributes/machine and process qualification parameters.

The built in templates build up or import material/machine/process/test data. Excel integration can be utilized in order to map and import custom templates for AM and various test methods. For example:

1. AM Electron beam deposition;
2. AM Directed laser beam deposition;
3. AM Powder bed fusion;
4. AM Fused Deposition Modeling;
5. Various Tensile Tests (Fracture Toughness K1C);
6. Various Hardness Test (Charpy Impact).

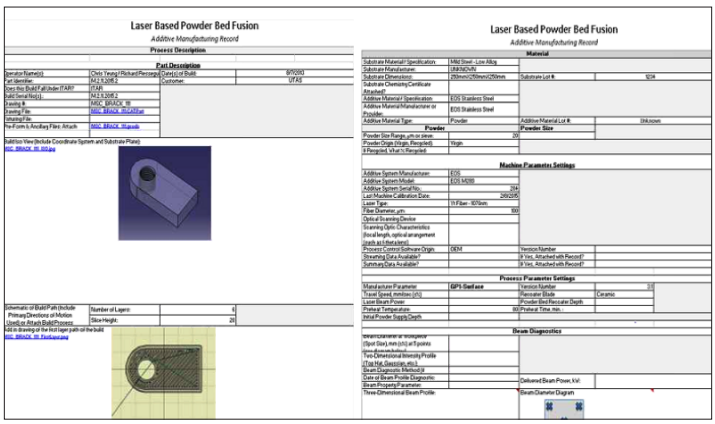


Figure 13: Sample of a Powder Bed Fusion Template

Sample of a laser based powder based Fusion template is shown in Fig. 13.

MaterialCenter provides built-in “Targets to Requirements“ on specification definitions and enables comparison of measurements to requirements supported by robust plotting capabilities as shown in Fig. 14 (a) and Fig. 14 (b)

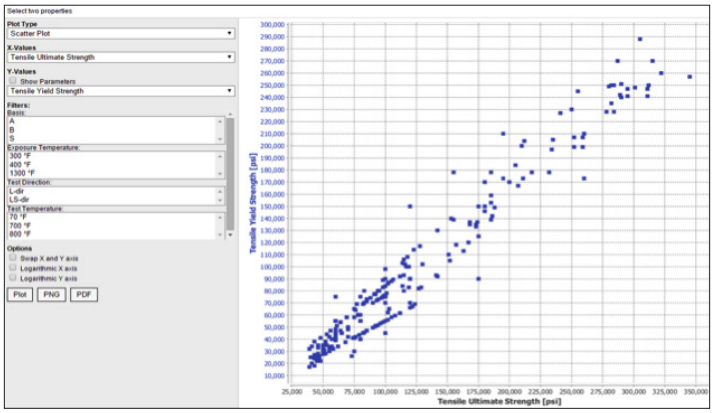


Figure 14 (a): Plotting of data (Targets to Requirements)

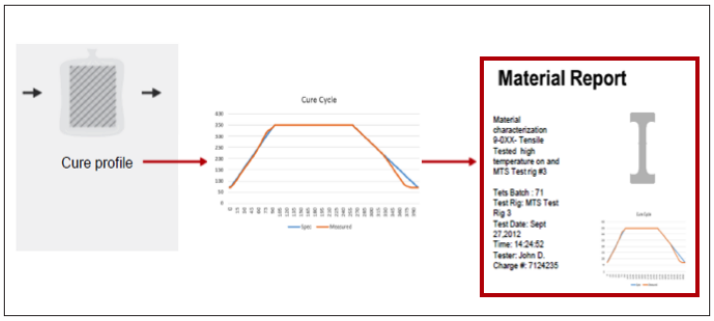


Figure 14 (b): Comparison of Specification vs. Measurured Cure Profile

Built in Analyzers in MaterialCenter perform various forms of statistical analysis and enrich the machine/process qualification. Fig. 15 (a) and 15 (b) trace the analysis and postprocessing of AM data. Some of the analytical capabilities are presented below.

1. Computation of average mass, thickness, peak load, peak stress, strain at break and modulus.
2. Standard deviation of all parameters listed in A.
3. Generates property curves:
   - Peak Load Vs. % Infill
   - Peak Stress Vs. % Infill
   - Modulus Vs. % Infill
   - Peak Stress Vs. Mass
4. Reduced Steps in Dynamic data analysis process.
5. Sequential process automation.
6. Integration of custom reduction algorithms via Python, JAVA, MATLAB or 3rd party CAE software.

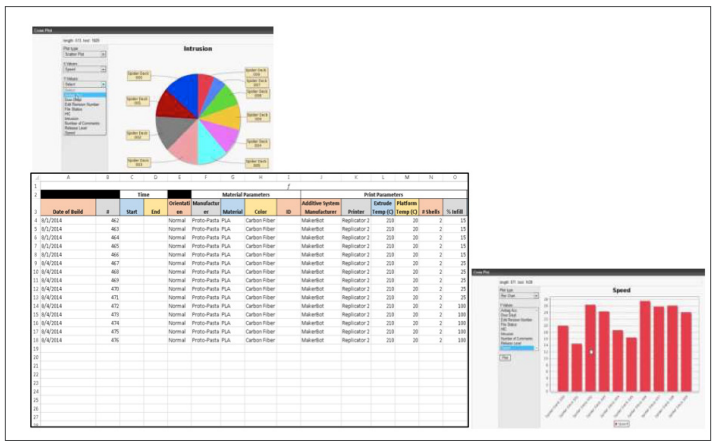


Figure 15 (a): Analysis/Post processing of data in MaterialCenter

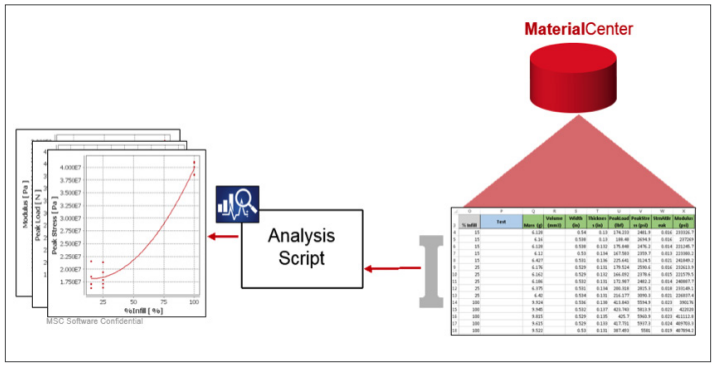


Figure 15 (b): Statistical analysis of AM material/machine/ process data in MaterialCenter

MaterialCenter has proven to be an effective solution to improve Additive Manufacturing workflow and data management, and helps design/produce quality AM parts and assemblies. Multifold benefits include the following:

1. Material qualification and traceability of metals/nonmetals/plastics;
2. Metrics for initial machine conditioning/process qualification;
3. New specification for material properties and testing methods.

8. CONCLUSIONS

Over the past 25 years, Additive Manufacturing has grown from a rapid prototyping process into a set of advanced technologies that are becoming more accessible to businesses, government organizations and individual customers worldwide. Although production of high-quality parts continues to be a challenge, there are commercial systems available to address all shortcomings.

MSC Software’s MaterialCenter, the next generation Material Lifecycle Management system, has been developed as “backbone“ to address AM challenges. This system is applied all across the AM product development lifecycle (design, development, simulation/prototype build and test) stages and covers the full scope of materials/machine/process/build qualification from concept to sustainment.

ABOUT MSC SOFTWARE

MSC Software is the global leader in multidiscipline simulation solutions that help companies improve quality, save time, and reduce costs associated with designing and testing manufactured products. MSC Software works with thousands of companies worldwide to develop better products faster with engineering simulation technology, software, and services. For additional information about MSC Software's products and services, please visit www.mscsoftware.com.

MSC Software's products and services are used by 900 of the top 1000 manufacturers in the world, across several industries including aerospace, defense, automotive, transportation, agricultural equipment, heavy machinery, medical devices, oil and gas, nuclear, consumer products, renewable energy, packaging, electronics, and shipbuilding.

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